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Civil, Mechanical, Military, and Naval;

WITH TECHNICAL TERMS

IN FRENCH, GERMAN, ITALIAN, AND SPANISH.

EDITED BY

BYRNE AND SPON.

DIVISION VI.

LONDON;
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK; 446, BROOME STREET.
1874.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

wheels utilize the impulsive force of the water, and to prevent their being submerged in flood time, M. Colladon places their axes upon movable supports, which renders them capable of being raised or lowered at pleasure. It is a very primitive kind of wheel, having a duty inferior to that of common

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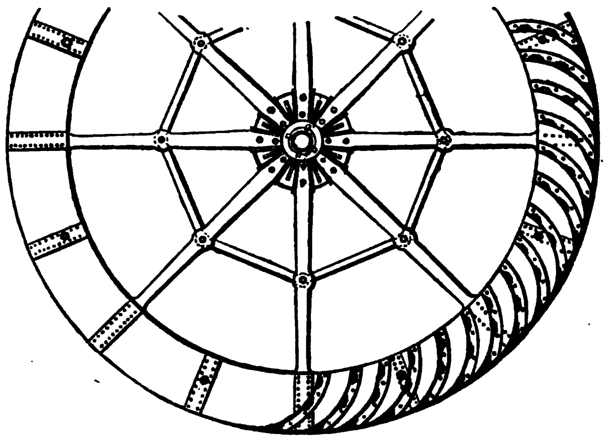

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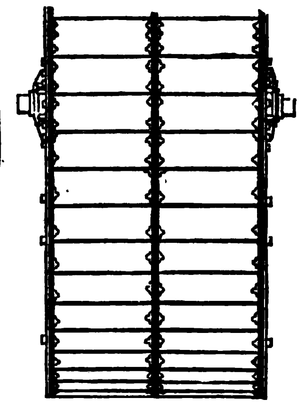

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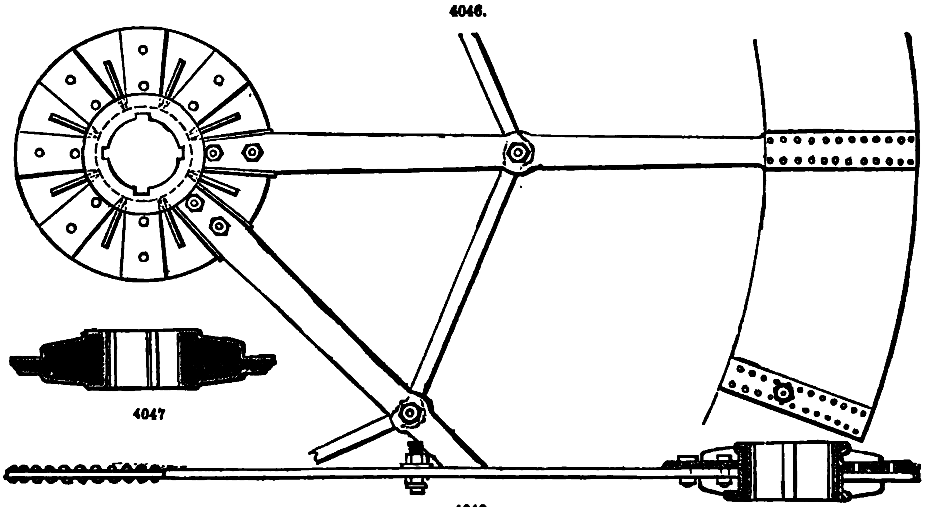

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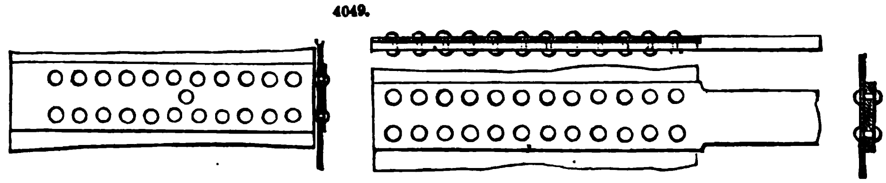

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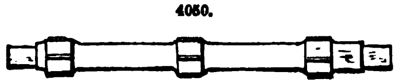

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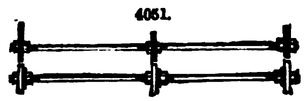

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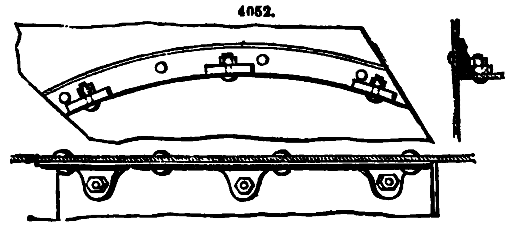

undershot wheels with straight floats, when well established. It is not suitable for wheels of great power, on account of the complication which is the consequence of the movability of the axis and the little rigidity which results from it.

Turbines.—Under the name of turbines are included those kinds of wheels which are constructed to utilize the *vis viva* possessed by the water in virtue of the velocity with which it arrives upon the wheel, this velocity being due to a height sensibly equal to that of the fall. The water is brought upon the buckets or blades of the turning portion of the wheel, or turbine proper, by channels distributed over the whole, or sometimes over a portion only of the circumference of the turbine; these with their various parts constitute the fixed part of the wheel, sometimes called the distributor.

Turbines may be erected upon either vertical or horizontal shafts. There are two classes of turbines with a vertical shaft. In those of the first class the water arrives horizontally upon the blades of the revolving part of the wheel through the interior of the latter, and issues horizontally, thus flowing away from the axis. This is Fourneyron's system. The revolving blades form thus a series of vertical cylindrical channels included between two horizontal walls. In those of the second class, called Euler's turbines, the water enters the wheel from above and issues from below, remaining thus at a constant distance from the axis.

Fourneyron's System of Turbines.—We will not stop to examine here the theoretical considerations involved in the conception of this kind of turbine; these considerations have been fully developed in another place. We will confine ourselves to giving a description of a turbine of this system, represented by Fig. 4053.

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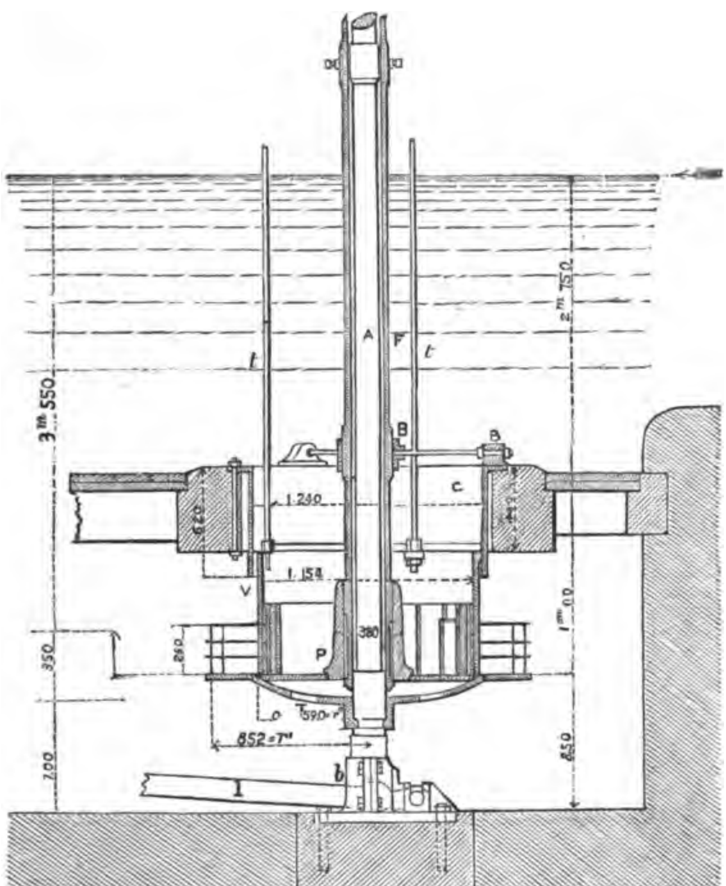

The turning portion, or turbine proper T, is erected upon a vertical iron shaft A, the lower end of which terminates in a pivot working in a socket *b*. This socket is bolted to a strong, hard stone built into the lower mill-race. A lever *l*, to which is attached an iron rod, regulates the height of the shaft, so as to remedy the wearing away of the pivot and keep the turning part of the wheel always in the same position. The vertical shaft A turns in a kind of sheath F of cast iron, bearing on its lower part the fixed portion of the wheel, or distributor P, which is furnished in its centre with a very elongated nave bored and fitted upon the sheath. This sheath F is centred and held in its position by a cast-iron collar B and three wrought-iron braces fixed as shown in the figure. The cylinder *c* serves as a guide to an inner cast-iron cylinder V, which constitutes the sluice of the turbine, and which is raised or lowered by sliding between moving and the fixed portions of the wheel. This sluice is worked by means of three vertical rods *t*, working into female screws

commanded by a single piece of mechanism to ensure an equal motion of the rods. The cylinder C is bolted upon the wooden floor of the water-chamber of the turbine. The fixed part P is provided with directing blades which run from the outer circumference; half of these blades reach the centre or nave, and half stop short at the mean circumference. Their use is to direct the water into the revolving part of the wheel.

One grave defect of this kind of turbine is the facility with which plants and leaves accumulate among the fixed blades; for this reason it is necessary to place a thick screen in some part above the wheel.

Theoretically this turbine should work beneath the tail-water to avoid a loss of fall; but practically it can be submerged only by a quantity equal to the lift of the sluice. If the turbine be placed out of the tail-water, and the sluice lifted to its full height, this turbine will be placed in its normal conditions with respect to the mode of action of the water; a pressure will be established in the channels of the moving part of the wheel, and the turbine will be revolved by reaction. If, on the contrary, the sluice be only partially lifted, the mode of action of the water may be changed; the veins of water, on leaving the fixed blades, enter the channels formed by the revolving blades, the capacity of which is, in that case, too great, and disturbances are produced which cause a decrease in the duty or percentage of work of the wheel.

Some experiments made with Fourneyron's turbine at a factory at Inval (France), with a low fall, and turning under water, gave the following results;—

Lift of the sluice	$0^{m}\cdot091$	$0^{m}\cdot145$	$0^{m}\ 200$	$0^{m}\cdot300$	$0^{m}\cdot345$
Percentage of work	0·49	0·58	0·67	0·69	0·71

From which it will be seen that the percentage of work diminishes with the lift of the sluice.

M. Fourneyron, to remove this very grave defect, divided the height of the moving portion of the wheel into three compartments (Fig. 4053), separated by horizontal partitions; but these partitions correspond to only three lifts of the sluice, and therefore remove the defect for only three particular positions of the sluice. It is a very imperfect remedy.

Among this class of turbines we must mention those of the Messrs. Williamson, of Kendal, in which the water is let into the wheel from without. Theoretically this arrangement possesses no advantage; it renders the construction of the turbine more complicated, and ought to be rejected, as well as Fourneyron's turbine itself, because it requires a volume of water and a velocity of rotation absolutely constant, conditions that can rarely be satisfied in practice.

When the fall is high, the turbine cannot in general be erected in water-chambers constructed of stone and wood, because the expense would be too great. In such a case the turbine is erected in a cast-iron tank fed by a conduit pipe from the upper mill-race. The height of the water in the upper race above the orifices of the revolving wheel must be sufficient to prevent the formation of hollows over these orifices; 1 mètre may be considered as a minimum. It is moreover necessary, for the free discharge of the water, to give a sufficient depth to the lower race beneath the wheel, to keep the mean velocity of the water there below $0^{m}\cdot60$ or thereabout. These conditions cannot always be satisfied with a turbine and an open water-chamber if the fall is rather a great one, the construction of the lower race in these cases being very expensive. This labour is considerably lessened by means of a very simple contrivance, invented and often applied by M. Girard, a French engineer.

Fig. 4054, to which we will return later, represents the application of this arrangement to one

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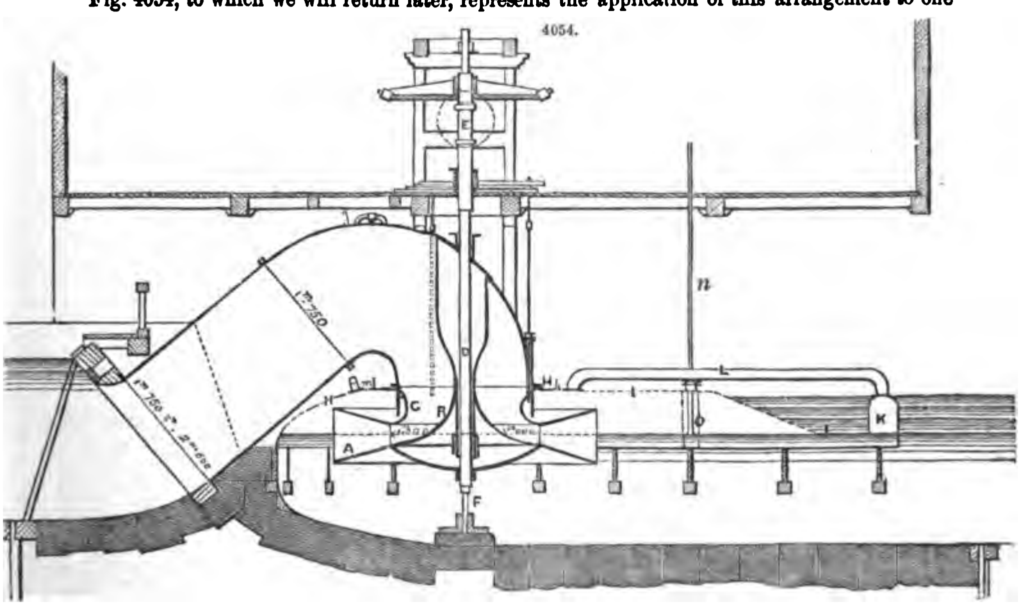


of Fourneyron's turbines. It consists of supplying the wheel by means of a siphon which raises the water to a level above that of the upper race, so that the revolving wheel may be placed up to

the lower level, and the formation of hollows is wholly avoided. The form of the siphon is studied with a view to guide the water in the most effective way on its arrival upon the revolving wheel, and to utilize consequently the impulsive force corresponding to the velocity which it has in the siphon.

The diametrical section of the turning wheel and the form of the blades have been modified by M. Girard, so that the turbine moves by free deviation, that is, the water flows in the buckets of the revolving wheel as in an open channel, so that the motion of this turbine satisfies as nearly as possible the theory relative to the motion of an isolated vein of water.

The sluice of the turbine represented in Fig. 4054 consists of a cast-iron cylinder, as in Fourneyron's turbine; but the diametrical profile of this cylindrical sluice is much more favourable to a proper guidance of the liquid veins: the water issues from the fixed portion of the wheel through a series of conical ajutages formed by the fixed blades, its inner wall R and that of the cylindrical sluice C. The revolving wheel A is fixed upon the bottom of a hollow cast-iron spindle or shaft D, which passes through the central casing of the tank, and terminates upwards in a kind of ear E, in which are placed the pivot and box. This box is screwed to the upper end of a central fixed shaft F, of wrought iron, passing through the hollow shaft and fixed below in a box or socket bolted to a hard stone set in the lower mill-race. This mode of construction renders the repairing and the greasing of this, the most delicate part of the wheel, very easy.

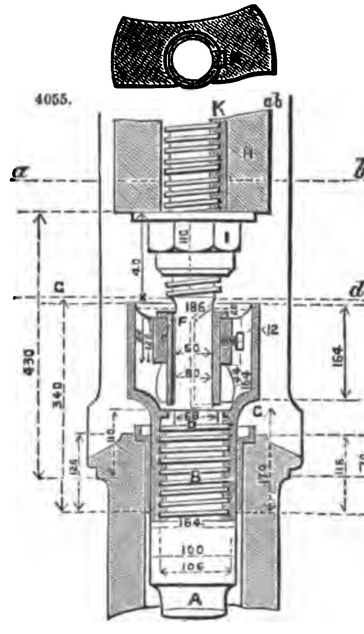
Fig. 4055 represents the details of the construction of the upper portion of the shaft D.

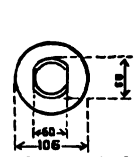
The pivot F terminates in a screw working into the head H of the hollow shaft, in which it is made to ascend or descend by means of the female screw I.

It often happens that the level of the lower race is variable; indeed this is the usual case. In such circumstances the turbine is placed with its lower side down to the lowest level, consequently in flood time the turbine is under water. This immersion of the revolving wheel is a favourable circumstance for Fourneyron's turbine when the sluice is wholly raised; but it is no longer favourable when circumstances do not admit of a complete raising of the sluice. And this case often occurs, because the capacity of the turbine is calculated with a view to obtain, even with a minimum fall, the power requisite for the mill. In such conditions the buckets of the revolving wheel are partially filled with the back-water, which is relatively at rest; the result is a shock and a consequent loss of work. To remove this grave defect, common to all systems of turbines, and to maintain sensibly constant the percentage of useful work in the conditions to which we have referred, M. Girard has invented a method of keeping the wheel free of water by means of compressed air driven under the revolving wheel by a small blowing machine driven by the turbine itself.

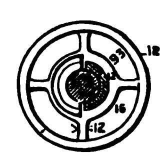
This very important improvement is shown in Fig. 4054, as having been applied to one of Fourneyron's turbines modified by M. Girard. The moving portion of the wheel is enclosed in a cast-iron cover H, perfectly air-tight, into which opens the pipe *m*, through which the compressed air is injected. The cover H runs down (I) to a reservoir of air K, in which the air collects, which is carried along mechanically by the water as it escapes from the turbine. A vertical tube *n*, terminating in a kind of reversed funnel *o*, serves to let off the superfluous air. The position of the lower edge of the funnel determines that of the *artificial* level of the water produced beneath the turbine by the injection of the air, so that the revolving wheel works in the air whatever the position of the level of the race may be. We shall see later what the advantage of this ingenious contrivance is.

Section through *a b*.





At lower end of pivot.



Section at *c d*.

Euler's Turbine.—In this kind of turbine the water enters from above. To avoid a loss of fall the lower face of the revolving wheel must be down to the lowest level of the back-water. If this level is constant the turbine will be always out of the water. This kind of wheel therefore possesses an incontestable advantage over Fourneyron's, which must work constantly under water in order to fulfil the same condition.

One of the first French constructors to apply Euler's principles to the construction of turbines was M. Fontaine, of Chartres. Figs. 4056 to 4058 represent a turbine erected by him at the mill of Vadenay, with some of its principal details. The adductor channel B opens into a water-chamber formed of two side walls of hydraulic masonry and a wooden framing A, and a vertical partition D, also of wood. The fixed part of the wheel F is bolted upon the framing A; the moving part H is fixed to the lower part of a hollow shaft L, the pivot of which is arranged as in Fig. 4055. The central column or fixed shaft is let into a cast-iron support K bolted to a hard stone set in the lower mill-race. The hollow shaft is enclosed in a cast-iron casing I in two pieces, which rises

a little above the highest level of the top-water. The sluice of the turbine consists of thirty-two small vertical gates V, Figs. 4057, 4058, sliding in grooves in the side cheeks of the fixed portion of the wheel; to each gate is attached an iron rod *t* fixed by two nuts to an iron ring *c*. This ring is suspended upon three or more vertical wrought-iron rods T, terminating upwards in a screw that works into the piece *m* turning in a groove. Each part *m* carries a spur-pinion; all of these pinions gear into a wheel *r*, so that by turning this wheel in either direction the rods T or the ring *c*, and consequently the thirty-two sluice-gates, are raised or lowered. Thus if it be required to reduce the discharge of water to one-third or one-fourth of the total capacity of the turbine, each of the sluices will be raised a third or a fourth of its total height.

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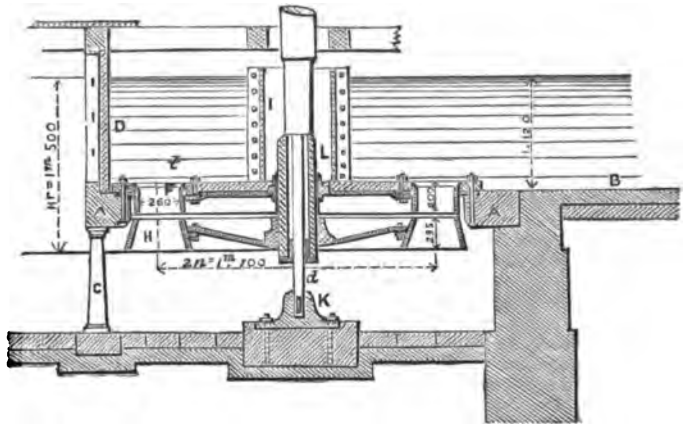

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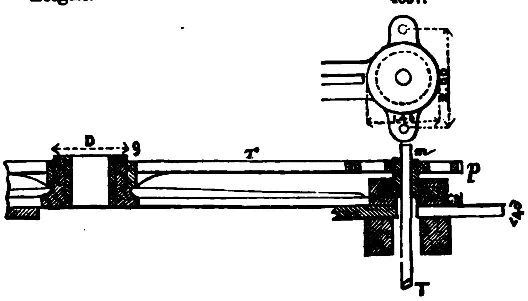

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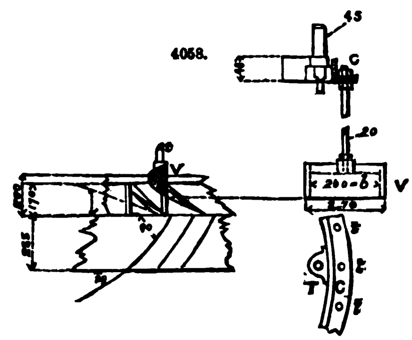

But to keep sensibly constant, notwithstanding the variations of the volume of water expended, the percentage of effective work of a turbine, the orifices of the distributor must, neglecting for the moment all other conditions, be fully opened. To make this clear we will give an example. Suppose that a turbine receiving the water throughout its circumference has to expend, during certain seasons of the year, only the half or a third of the volume of water corresponding to its total capacity. There are two ways of reducing the expenditure of the turbine so as to make it exactly equal to the volume furnished by the stream. The first, employed by M. Fontaine in the turbine which we have just described, consists in proportionately reducing the opening of all the orifices of the distributor. This is a very bad way, and it greatly reduces the percentage of work at the very time when it can least be afforded, namely, when the stream is low. The second way, the best and most rational applications of which we owe to M. Girard, consists in opening only that number of orifices which correspond to the volume to be expended; this is the principle of *partial sluices* applied to turbines. Many examples of the application of this principle were shown in the Paris Exhibition of 1867; but as all of them were very objectionable from some point of view, we will not attempt to describe them here. The Exhibition did not, indeed, show the progress which has been made during the last few years in the construction of turbines. This progress we will show in our article on TURBINES. To this end it will be necessary here to call attention to a few generalities applicable to all systems of turbines.

The form of the directing blades being given, that of the moving blades is deduced so as to allow the water to enter without shock; to effect this, the first element of the blades must be directed according to the *relative* velocity of the water at its entrance. The ratio of the *absolute* velocity with which the water issues from the orifices of the fixed portion of the wheel, with the linear velocity at the periphery of the wheel, may be taken arbitrarily; the value of this ratio has, however, an influence on the percentage of work.

If the linear velocity of the wheel is nearly equal to that of the water, the wheel is called a *high-pressure* turbine. The choice of this proportion enables us to use a wheel of a relatively small diameter, with a large volume of water. The adoption of a high-pressure turbine is often rendered necessary;—1, by the necessity of expending a large volume of water under a low fall (1 mètre and even less); 2, by the diminished cost of the wheel and the works requisite for its establishment; 3, by the advantage of obtaining a greater velocity in the shaft of the turbine, which usually simplifies much the transmission of the motion. But the percentage of work in wheels of this kind rarely exceeds 0·65. Therefore in most cases, even on rather high falls, it is better to give the

turbine a velocity equal to about half that of the water. This proportion characterizes the wheels known as *low-pressure* turbines, in which the percentage of work may always be considerably greater than that of high-pressure turbines working under the same conditions of fall and volume.

The only important and rational improvements in the construction of turbines on Euler's system are due to M. Girard. Fig. 4059 represents one of Girard's turbines with an open water-chamber, the partial sluiceage of which consists of a series of vertical sluices similar to those of Fontaine's turbine explained above; but instead of their being all raised at once, they are raised one after another by means of a kind of rack and pinion communicating with a governor placed above the wheel, Fig. 4059, A B, *b*. This kind of sluice works perfectly, and may be adapted to the action of an automatic regulator.

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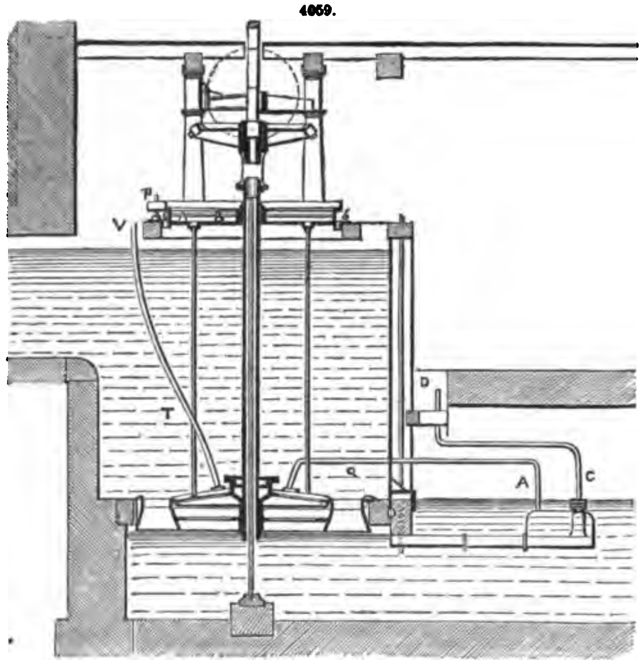


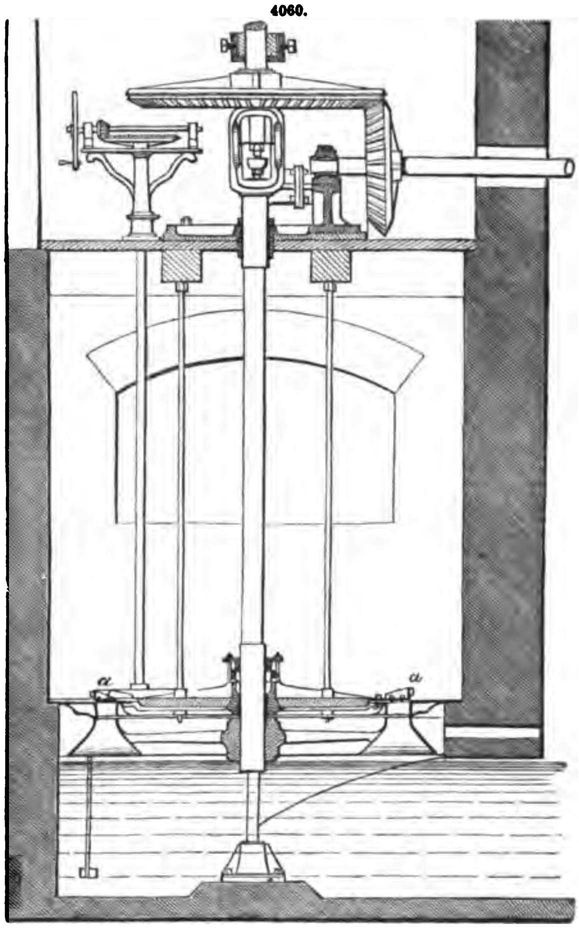
The objection to which we called attention in the case of Fourneyron's turbine when the level of the back-water is variable, exists also in those of Euler's system. M. Girard, however, removes this objection by clearing the wheel of water by means of compressed air in the manner we have before described. Fig. 4059 shows the arrangement of the hydro-pneumatic apparatus of M. Girard applied to a turbine with an open water-chamber. Numerous experiments have been made to test its value. Some of these we give in the following Table, compiled from M. Girard's works on the subject.

Experiments made with Three of Girard's Low-pressure Turbines, with Partial and Independent Sluices, and Working out of the Water.

Description of the Wheel.	Fall.	Number of Sluices open.	Percentage of useful effect to the gross work. Working out of the water.	Working under water.	Advantage of working with compressed air.
Paper Mill at Egreville (Seine-et-Marne).					
$2r = 2^{m}\cdot48$ 40 fixed curves ..	1·79	10 (out of 40) 0·25	0·70 to 0·75	0·58 to 0·68	$\frac{0\cdot70 - 0\cdot58}{0\cdot58} = 0\cdot21$
40 moving curves ($h' = 0\cdot30$) ..	1·63	16 " 0·40			
$T^{u} = 30$ horse-power under a minimum fall of 1 mètre ..	1·60	20 " 0·50			
Persian India-rubber Factory (Seine-et-Oise).					
$2r = 1\cdot70$ 80 fixed curves ..	2·710	24 (out of 80) 0·30	0·78 to 0·80	N.B.—The turbine is cleared of water naturally.	
54 moving curves ($h' = 0\cdot20$) ..	2·660	32 " 0·40			
	2·535	36 " 0·45			
Spinning Mill of Amilly (Loiret).					
$2r = 3\cdot600$	1·80	14 (out of 80) 0·17	0·69		
80 fixed curves		18 " 0·22	0·71		
60 moving curves ($h' = 0\cdot36$) ..		24 " 0·30	0·73		
		30 " 0·375	0·77		
		36 " 0·45	0·78		
		48 " 0·60	0·80		
		48 " 0·60	..	0·70	$\frac{0\cdot80 - 0\cdot70}{0\cdot70} = 0\cdot14$

Fig. 4060 represents the diametrical vertical section of a turbine with an open water-chamber on Girard's system, in which the water is admitted only upon two opposite quarters of the periphery. The sluice consists of two sectors or valves *a a*, each worked by a special mechanism, one of which is shown in the figure. We ought to call attention here to the excellent and strong arrangement of the supports of the vertical shaft of the turbine as well as those of the mill-shaft.

4060.



As the two valves work *independently* of each other, only one need be opened in seasons when the water is low; this is favourable to the maintenance of a good percentage of useful effect. It is evident that this turbine which, at most, is fed upon half its circumference, must not work under water. If the level of the back-water is variable, the turbine should be placed so as to utilize the whole fall in seasons of low water; in flood time it is kept clear of water by means of compressed air.

A turbine of this kind is applicable to the case of a very variable, but not large, volume of water (1000 to 1500 litres a second at the most), with a moderate fall, or in the case of very variable volumes with a high fall. In the latter case the turbine is placed in a closed iron tank. Often the great height of the fall is not the only reason for the adoption of a closed tank. Sometimes the conformation of the place where the wheel has to be erected, or some other local reason, leads to the adoption of the iron tank, in which the water is brought by a pipe, in place of the stone and timbered water-chamber.

Fig. 4061 represents a turbine with a close tank on Girard's system, fixed under a low fall: the figure in question shows the arrangements to be given in such a case to the hydro-pneumatic apparatus. The wheel is fed with water throughout its periphery: and the sluice consists of ten or twelve sliding valves moving horizontally. The form of the tank is designed to enable the water to enter readily, and to prevent any loss of force through a sudden change of velocity. The motion of the slide-valves clears away any obstructions that may accumulate. As each valve corresponds to several orifices in the fixed or guiding part of the wheel, and as each valve should be fully opened in order not to reduce the proportion of useful

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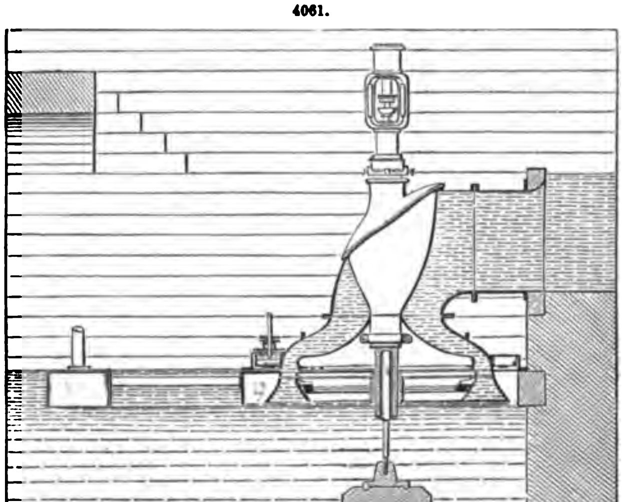

effect of the corresponding orifices, it follows that we cannot by means of this system of sluice reduce the volume of water so gradually as by means of the two independent valves mentioned above. These considerations led M. Girard to combine these two systems of sluices.

Figs. 4062, 4063, represent this arrangement for the case of a turbine with an open water-chamber. The following references will render a description unnecessary;—A, moving portion of the wheel; B, fixed portion; C, fixed column or shaft; D, hollow spindle; E, stuffing box, serving as an axis to the register-valve; K, differential register-valve with one blade covering 0·10 of the circumference; L, spindle commanding the register-valve; P, spindle commanding the toothed cam-sector; Q, toothed cam-sector working the slide-valves; R, V-piece working the slide-valves; S, hollow columns; T, movements of the slide-valves; U, copper guides; V, cast-iron slide-valves.

It will be readily seen that by uniting the slide-valves and the register-valve, we may fully open a number of orifices exactly necessary and sufficient to use only the volume of water furnished by the stream; there is at most but one, the register-valve, whose orifices are only partially covered; but this is unimportant.

When a turbine has to expend a relatively small volume of water under a high fall (5 mètres and above), there is an advantage in supplying it with water upon a portion only of the circumference, because in that case it may have a larger diameter, and consequently revolve a less number of times than if it were supplied throughout its circumference. We may then adopt the sluice

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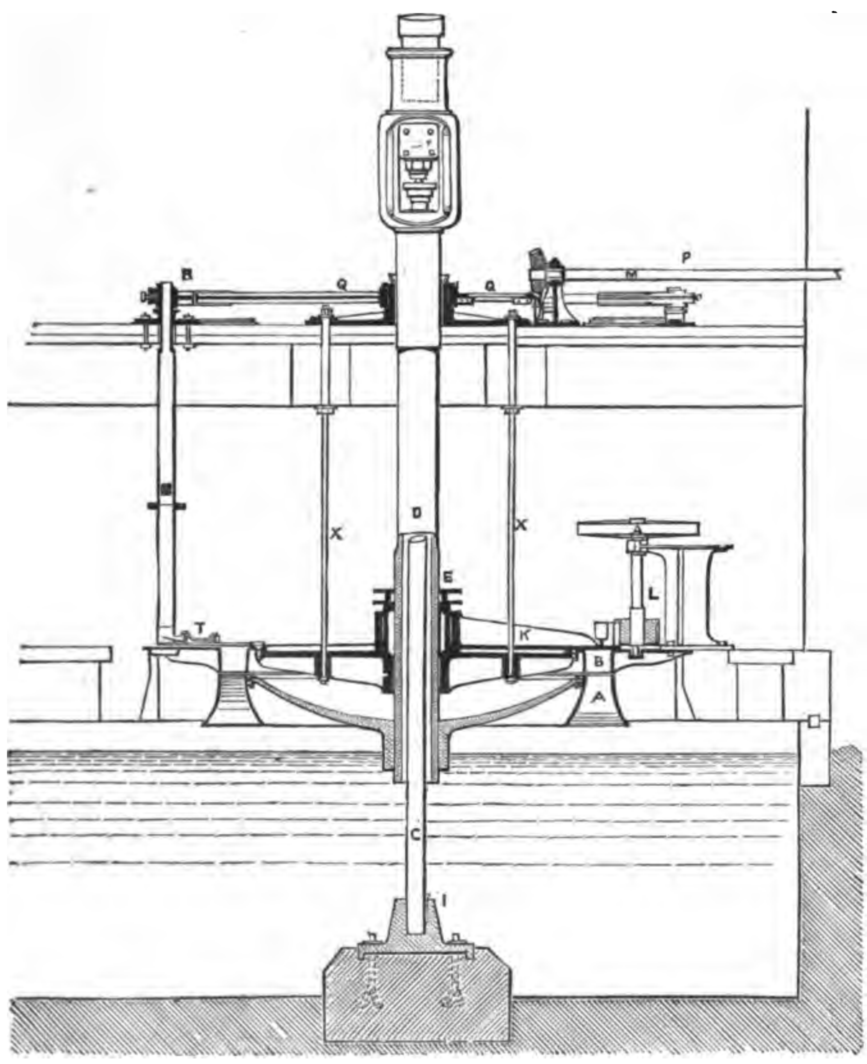


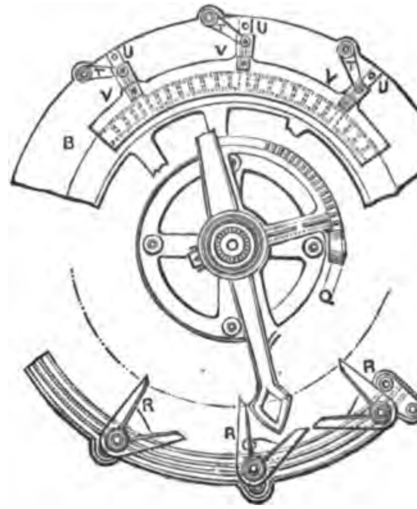
with two independent register-valves. But in many cases M. Girard prefers to supply the wheel upon only $\frac{1}{4}$ or $\frac{1}{6}$ of its circumference in order that its orifices may be larger, and so, less liable to

be blocked up. These reasons led him to construct the turbine with a *lateral injector*, represented in Fig. 4064. The sluice of this turbine consists of a simple circular sector or valve, from which M. Fontaine first got the idea of a roller-valve. These turbines possess the immense advantage of being almost wholly open, and therefore are easily inspected, cleaned, and repaired. But it will be seen that they are not suitable to a varying level of back-water, as they cannot work under water (being supplied upon only a small portion of their circumference), and the *hydro-pneumatic* apparatus is not applicable to them.

Turbines with a vertical axis possess a delicate part, namely, their pivot, which, if it has to support too heavy a load, or if it turns too rapidly, is liable to become heated. This defect is of great importance in high-fall turbines, the vertical spindle of which is often very long and heavy, and has to carry besides the weight of toothed wheels or pulleys. M. Girard has completely removed this difficulty by the application of two hydraulic pivots, represented in Fig. 4065. This pivot is placed at the bottom of the hollow spindle, that is, upon the floor of the lower mill-race.

It consists of two cast-iron plates, P and P′, provided with grooves. The upper plate P is wedged upon the bottom of the hollow spindle M, beneath the revolving wheel. The lower plate P′ is cast with the part which receives the

4063.



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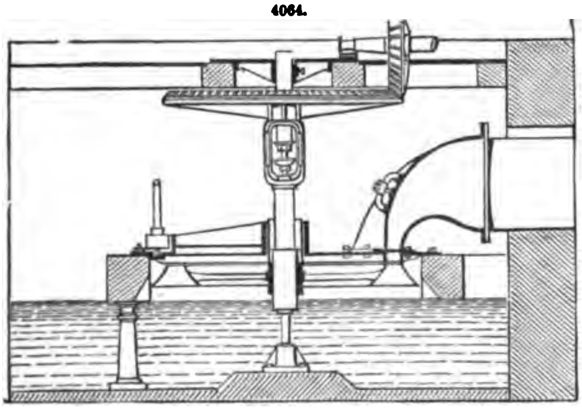

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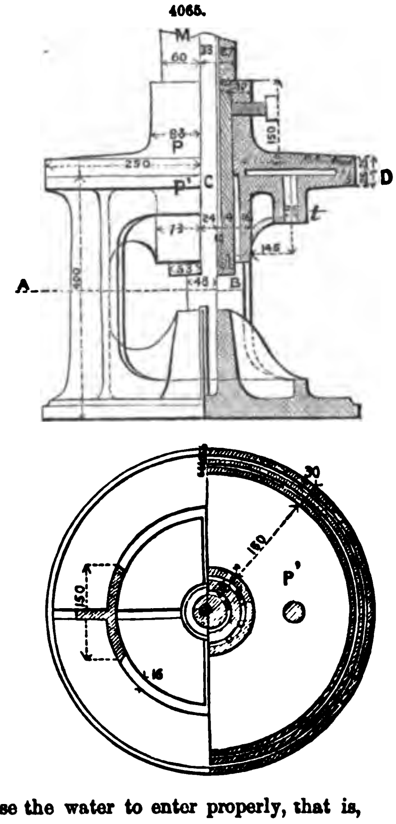


bottom of the central column or fixed spindle; for not withstanding the employment of the hydraulic pivot, M Girard, as a precautionary measure, employs the ordinary pivot suspended to the upper portion of the hollow spindle, as already explained.

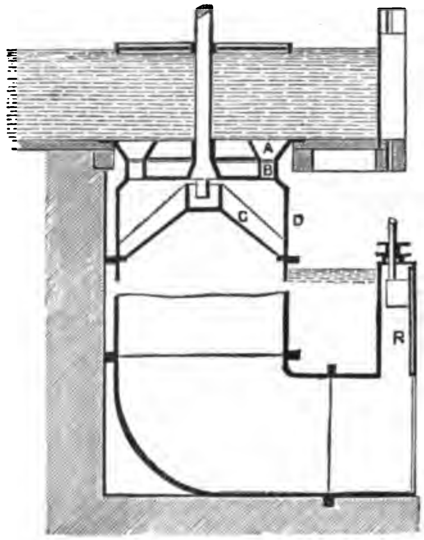
A small pipe brings the water from the upper race between the two plates of the pivot by means of the tubulure *t* cast in the lower plate. Of course the diameter of these plates must be calculated according to the weight they have to support and the height of the fall. We have seen this hydraulic pivot applied in many instances, and in all with perfect success.

Jonval's Turbine.—Fig. 4066 represents a turbine on Euler's system, with the particular arrangements introduced by Jonval. This turbine may be fixed in any intermediate point between the upper and the lower levels of the fall, taking care only to leave above the fixed portion of the wheel A a sufficient height of water to cause the water to enter properly, that is, without eddies or hollows.

The moving portion of the wheel B is wedged upon an iron spindle, the pivot of which turns in a step or bearing in the centre of a support, arranged as shown in the figure, and bolted to the tank or cistern D, which encloses the turbine and comes down to the floor of the tail-race, where it curves horizontally to allow the water to flow out. The turbine is not provided with

sluices, so that the orifices of the distributor are always fully open. The expenditure of water is regulated by means of a vertical sluice-gate R, placed against the discharge orifice or the well. By closing this gate more or less, the expenditure of the turbine is diminished in proportion to the diminution of volume in the stream. This arrangement is a very bad one;—1, because it produces a contraction which occasions a loss of fall that becomes all the greater as the volume of water diminishes; 2, because the orifices remaining fully open, the velocity of the water is diminished, and the velocity of the turbine must be proportionately reduced if its percentage of useful work is to be maintained. But this condition of giving a variable velocity to the turbine is incompatible with the exigencies of most mills.

4066.



M. André Köchlin has endeavoured to remove this defect by two means. The first and cheapest, but least effective, consists in reducing the breadth of the orifices by means of mitre-wedges. In this way, when the stream is low, the velocity of the water as it enters the turbine may be kept about the same, so that the velocity of the wheel may also be maintained without much variation in the proportion of useful work. But if it were attempted to make this means really effective, it would become impracticable; for as many series of wedges would be required as there were different values of the volume of water furnished by the stream. The other means, which is much more expensive, consists in erecting, upon a stream whose volume of water varies, two or three of Jonval's turbines, when a single one of Girard's, with a partial sluice, would suffice. The capacities of these multiple turbines are calculated in such a way that the quantity of water used by each shall undergo only very slight variations. In flood times, all the turbines are set going; when the water is low, on the contrary, that one only is used which has been erected specially for this season. This artifice is an excellent one for the millwright; but it increases considerably the original outlay. It does, however, possess the advantage of dividing the motive power among several wheels, which enables the mill to keep working while repairs are being executed.

As Jonval's turbine may generally be placed, in the case of moderate or high falls, considerably above the highest back-waters, they may be inspected and repaired in any season without it being necessary to draw off the water previously.

Turbines with a Horizontal Axis.—By applying the theoretical and practical rules which serve in the construction of turbines with a horizontal axis, many engineers and millwrights have erected water-wheels having a horizontal axis, which utilize the water in precisely the same way as ordinary turbines. These are generally known as *turbines with a horizontal axis.*

The Paris Exhibition of 1867 contained only two kinds of these turbines. One was exhibited by a firm of builders at Jenbach (Tyrol). But it is merely a Jonval-Köchlin turbine turned the other way up. Through a horizontal cylindrical tube, which forms the tank or well of the turbine, passes the shaft upon which the wheel is fixed. A circular channel cast in one end of this tube and perpendicular to its axis, receives the feed-pipe; the water is guided upon the wheel by fixed blades, arranged as in Euler's turbine. At the other end of the tube and also perpendicular to it is another similar channel through which the water is discharged; this orifice is provided with a valve for the purpose of regulating the expenditure of water.

These are the chief arrangements of the Jonval-Köchlin turbine. There are many objections to be urged against them. The channels by which the water is introduced and discharged being perpendicular to the axis of the wheel, there is a considerable loss of fall consequent on the sharp angles. The valve which serves to regulate the expenditure of water, by acting upon the discharge orifice, constitutes a faulty arrangement, as we have seen above; and as the wheel works constantly immersed, it must be supplied with water throughout its circumference, if the loss of work which we have already pointed out is to be avoided, and which cannot be removed here by means of compressed air. This necessity led to the adoption of the valve placed against the discharge orifice; but the remedy is a very imperfect one. Let us add, that for streams having a small volume of water and a very high fall, the adoption of this kind of turbine, as well as Fourneyron's, necessitates the giving a small diameter to the turbine, with very small orifices which are easily blocked up. Besides this, we have a great velocity in the shaft of the turbine, and consequently many chances of breakages and repairs.

Two small models of turbines with a horizontal axis on Canson's system were also exhibited. These turbines are of a very simple and primitive construction. The wheel, arranged like that of Fourneyron's turbine if its axis were placed horizontally, is erected upon a horizontal shaft resting upon two ordinary cushions. The water is directed against the lower blades of the wheel from the interior by a simple pipe, the single orifice of which is opened more or less by means of a small vertical sluice. The water is therefore very badly guided on issuing from the pipe, so that the proportion of useful work is small, hardly above 50 per cent. of the gross work expended.

This kind of turbine is, however, frequently met with in the south of France, where the pro-

gress of science has only begun to make itself felt. But it is fast disappearing from mills where a rational utilization of water-power is recognized.

Turbines with a horizontal axis possess, however, special advantages when, as in Canson's system, they receive the water upon a portion only of their circumference. These advantages are the following;—The whole periphery of the wheel being exposed to sight, it is easy to observe the way in which the water acts, and to keep the blades and the other parts of the turbine in a good condition; the absence of a pivot and all water-tight fittings for the shaft, renders the machine less delicate, allows it to revolve very rapidly without danger, and diminishes consequently the chances of accidents; as the wheel is supplied with water upon a portion only of its circumference ($\frac{1}{4}$ at the most), it follows, as in the case of turbines with a vertical axis and lateral injector, that the orifices of the *fixed sector* or *injector* and those of the wheel present relatively larger dimensions, and consequently less liable to be blocked by the rubbish brought down by the water; and lastly, the level of the back-water may vary in a certain degree without lessening the proportion of useful work, since the turbine may work immersed in the back-water to a depth equal to the versed sine of the arc upon which the water is brought. But to realize all these advantages, the blades, both moving and fixed, must have all the improvements of form and dimensions introduced into the best vertical turbines.

The only horizontal turbines which satisfy all these conditions are those of M. Girard. These turbines may be applied with equal success to very high and to very low falls. The Exhibition of 1867 contained no specimen of these remarkable wheels; but we will give examples of two kinds here.

Fig. 4067 represents a small turbine on this system, adapted for a very high fall and a small volume of water. This model is equally applicable as the special motor of a machine-tool or of a lifting machine, such as paper machines, cranes, and so on. The wheel a is fixed upon the end of

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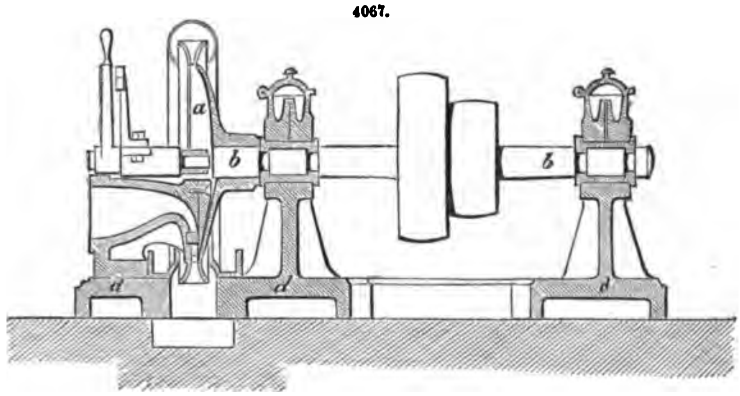


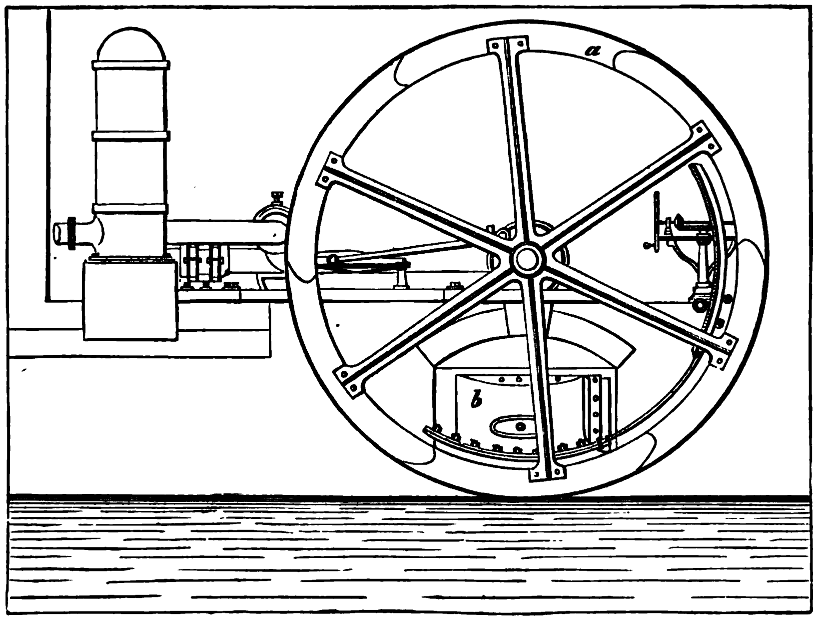
a horizontal shaft b b, which is provided with one or more pulleys. The water is brought through a pipe bolted upon the orifice c of the injector. The whole is erected upon a single bed-plate, which thus renders all the parts solid with each other.

Fig. 4068 represents a large turbine which works directly and without gearing a horizontal water-pump with a plunger-piston and double action, of which M. Girard has lately made many and remarkable applications for raising water for supplying towns. It will be easily seen that this turbine may be applied (as indeed it has been) to any kind of mill. The wheel a is erected upon a horizontal wrought-iron shaft, and rests upon two cushions. The injector b supplies the turbine upon a small portion only of the circumference, which allows large orifices to be used.

The proportion of useful work reached by these turbines may be from 75 to 80 per cent. of the gross work expended. This kind of turbine is suitable to low or moderate falls and large volumes of water. It may be advantageously substituted for any other kind of wheel required to give great power with a low fall. In support of our assertion we mention;—1, the turbines of $5^{m}\cdot 20$ diameter erected by MM. Callon and Girard for supplying water to the town of Le Mans, which give each an effective power equal to 25 horse-power under a fall of 1 mètre; they make from ten to eleven revolutions a minute, and they each drive directly and without gearing two horizontal plunger-piston double-action pumps which force the water up into the reservoirs of the town. Their useful work, *in water raised*, according to the official experiments made by M. Dupuit, the representative of the interests of the town of Le Mans, is equal to 0·56 of the gross motive work of the fall; hence we may conclude that as the proportion of the useful work of the pumps is 75 per cent., that of the wheels in question is 75 per cent.; 2, the four turbines of $11^{m}\cdot 60$ in diameter erected by M. Girard for the water-works of Paris, at Saint Maur, on the Marne, which supply the large reservoirs recently constructed at Ménilmontant. Each of these wheels gives an effective power equal to 120 horse-power, under a fall that varies from 5 to $2^{m}\cdot 50$. Each of them works directly and without gearing a pump similar to those described above. Experiments made upon these powerful engines by Parisian engineers have shown a proportion of useful work in water raised of 64 per cent. A remarkable peculiarity of these wheels is their sluice. It consists of a series of vertical iron gates or hatches, each worked by a piston moving in a double-action cylinder, into which the air from the pump reservoirs is let. The driver has merely to turn

on or off certain cocks to raise or lower the sluices; this contrivance requires no labour, and it is capable of stopping the wheel in a few seconds. This latter quality is of great importance in case of accidents.

4068.



In bringing our remarks on turbines to a close we will give, Fig. 4069, a sketch of a particular kind of turbine with a horizontal axis, called the *screw-wheel*, designed to utilize the power of large streams having a very low fall (from $0^{m}\cdot50$ to $0^{m}\cdot60$) and a considerable volume of water. Two of these wheels were erected some time ago by M. Girard, at Noisiel-sur-Marne. As a reference to the figure will show, the wheel has its axis in that of the canal, and turns consequently in a plane

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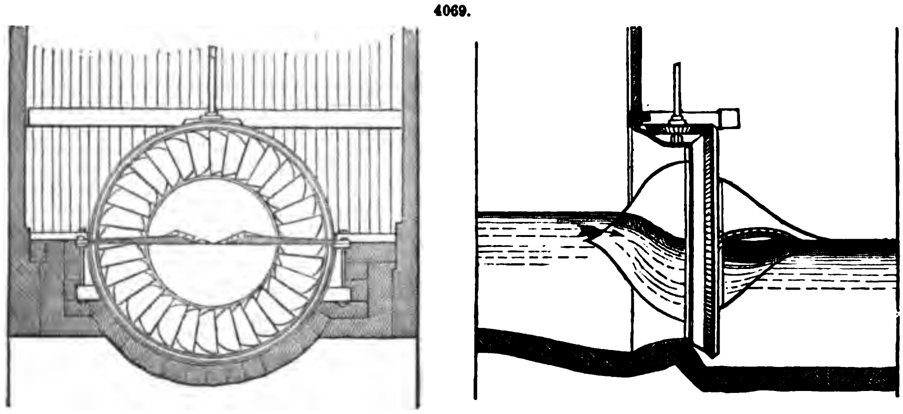

perpendicular to the direction of the water. This kind of turbine has no sluice; the volume of water which it expends increases in proportion as the fall diminishes, and diminishes, on the contrary, in proportion as the fall increases. We think it might be very advantageously applied to our large streams, in conjunction with the large turbine-wheel described above.

The variety of hydraulic machines that we next introduce is a water-wheel, which belongs to the turbine class, and which was invented and brought successfully into use by James Thomson, engineer, Belfast.

In this machine the moving wheel is placed within a chamber of a nearly circular form. The water is injected into the chamber tangentially at the circumference, and thus it receives a rapid motion of rotation. Retaining this motion it passes onwards towards the centre, where alone it is free to make its exit. The wheel, which is placed within the chamber, and which almost entirely fills it, is divided by thin partitions into a great number of radiating passages. Through these passages the water must flow on its course towards the centre; and in doing so it imparts its own

rotatory motion to the wheel. The whirlpool of water acting within the wheel-chamber, being one principal feature of this turbine, leads to the name *Vortex* as a suitable designation for the machine as a whole.

The vortex admits of several modes of construction, but the two principal forms are the one adapted for high falls and the one for low falls. The former may be called the high-pressure vortex, and the latter the low-pressure vortex. Examples of these two kinds, in operation at two mills near Belfast, are delineated in Figs. 4070 to 4072, with merely a few unimportant deviations from the actual constructions.

Figs. 4070, 4071, are respectively a vertical section, and a plan of a vortex of the high-pressure kind in use at the Low Lodge Mill, near Belfast, for grinding Indian corn. In these figures A A is the water-wheel. It is fixed on the upright shaft B, which conveys away the power to the machinery to be driven. The water-wheel occupies the central part of the upper division of a strong cast-iron case C C; and the part occupied by the wheel is called the *wheel-chamber*. D D is the lower division of the case, and is called the *supply chamber*. It receives the water directly from the supply pipe, of which the lower extremity is shown at E, and delivers it into the outer part of the upper division, by four large openings F, in the partition between the two divisions. The

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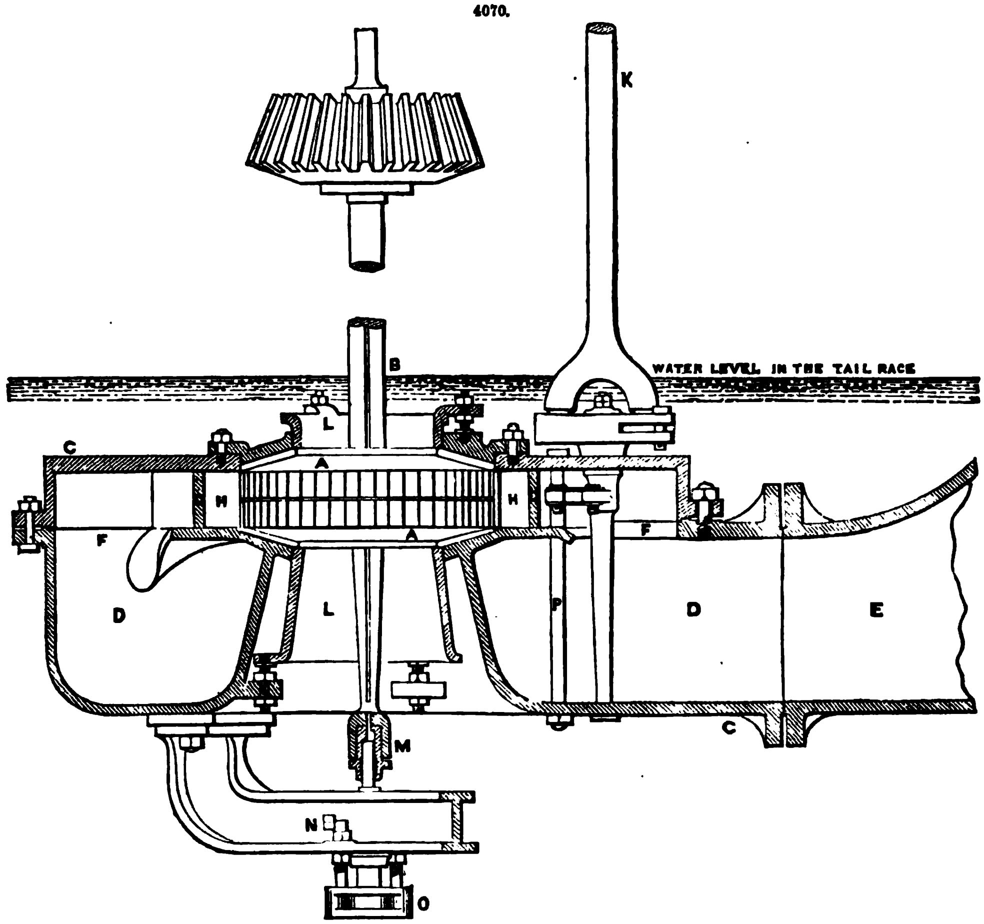

outer part of the upper division is called the *guide-blade chamber*, from its containing four guide-blades G, which direct the water tangentially into the wheel-chamber. Immediately after being injected into the wheel-chamber the water is received by the curved radiating passages of the wheel, which are partly seen in Fig. 4071, at a place where both the cover of the wheel-chamber and the upper plate of the wheel are broken away for the purpose of exposing the interior to view. The water, on reaching the inner ends of these curved passages, having already done its work, is allowed to make its exit by two large central orifices, shown distinctly on the figures at the letters L L; the one leading upwards and the other downwards. It then simply flows quietly away; for the vortex being submerged under the surface of the water in the tail-race, the water on being discharged wastes no part of the fall by a further descent. At the central orifices, close joints between the case and the wheel, to prevent the escape of water otherwise than through the wheel itself, are made by means of two annular pieces L L, called *joint-rings*, fitting to the central orifices

of the case, and capable of being adjusted, by means of studs and nuts, so as to come close to the wheel without impeding its motion by friction. The four openings H H, Figs. 4070, 4071, through

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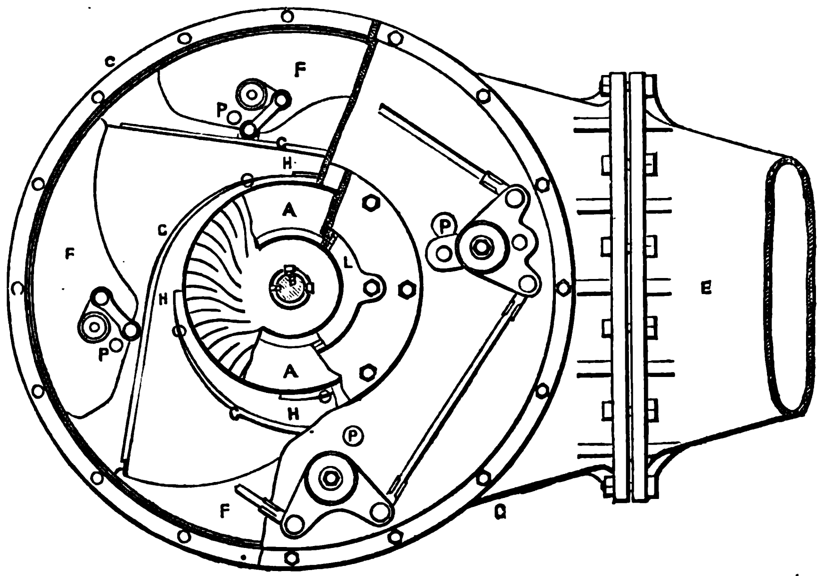

which the water flows into the wheel-chamber, each situated between the point or edge of one guide-blade and the middle of the next, determine by their width the quantity of water admitted, and consequently the power of the wheel. To render this power capable of being varied at pleasure, the guide-blades are made movable round gudgeons or centres near their points; and a spindle K is connected with the guide-blades by means of links, cranks, &c., in such a way that when the spindle is moved, the four entrance orifices are all enlarged or contracted alike. This spindle K, for working the guide-blades, is itself worked by a handle in a convenient position in the mill; and the motion is communicated from the handle through the medium of a worm and sector, which not only serve to multiply the force of the man's hand, but also to prevent the guide-blades from being liable to the accident of slapping, or of being suddenly shut from the force of the water constantly pressing them inwards. The gudgeons of the guide-blades, seen in Fig. 4071 as small circles, are sunk in sockets in the floor and roof of the guide-blade chamber; and so they do not in any way obstruct the flow of the water.

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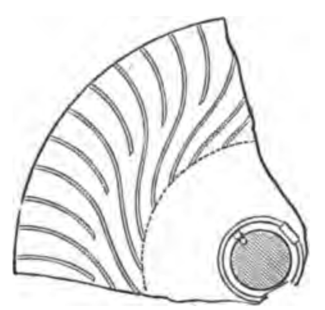

Part of the wheel, Fig. 4071, on a larger scale, to show the form of the vanes more accurately.

M, in Fig. 4070, is the pivot-box of the upright shaft. It contains, fixed within it, an inverted brass cup shown distinctly on the figure; and the cup revolves on an upright pin or pivot with a steel top. The pin is held stationary in a bridge N, which is itself attached to the bottom of the vortex-case. For adjusting the pin as to height a little cross bridge O is made to bear it up, and is capable of being raised or lowered by screws and nuts shown distinctly on the figure. Also for preventing the pin from gradually becoming loose in its socket in the large bridge, two pinching screws are required, of which one is to be seen in the figure. A small pipe fixed at its lower end into the centre of the inverted brass cup, and sunk in an upright groove in the vortex-shaft, affords the means of supplying oil to the rubbing surfaces, over which the oil is spread by a radial groove in the brass. A cavity, shown in the figures, is provided at the lower part of the cup, for the purpose of preventing the oil from being rapidly washed away by the water. Great stress being laid on the supposed necessity for oiling the pivots of turbines by Continental engineers, J. Thomson was led to endeavour to find and adopt the best means for oiling pivots working under water. The oiling, however, is a source of much trouble; and he has found in the course of his experience that pivots of the kind described above, made with brass working on hard steel, and with a radial groove in the brass suitable for spreading water over the rubbing surfaces, will last well without any oil being supplied.

Four tie-bolts, marked P, bind the top and bottom of the case together, so as to prevent the pressure of the water from causing the top to spring up, and so occasioning leakage at the guide-blades or joint-rings.

The height of the fall for this vortex is about 37 ft., and the standard or medium quantity of

water for which the dimensions of the various parts of the wheel and case are calculated is 540 cub. ft. a minute. With this fall and water-supply the estimated power is 28 horse-power, the efficiency being taken at 75 per cent. The proper speed of the wheel, calculated in accordance with its diameter and the velocity of the water entering its chamber, is 355 revolutions a minute. The diameter of the wheel is 22¼ in., and the extreme diameter of the case is 4 ft. 8 in.

A low-pressure vortex, constructed for another mill near Belfast, is represented in vertical section and plan, in Figs. 4073, 4074. This is essentially the same in principle as the vortex

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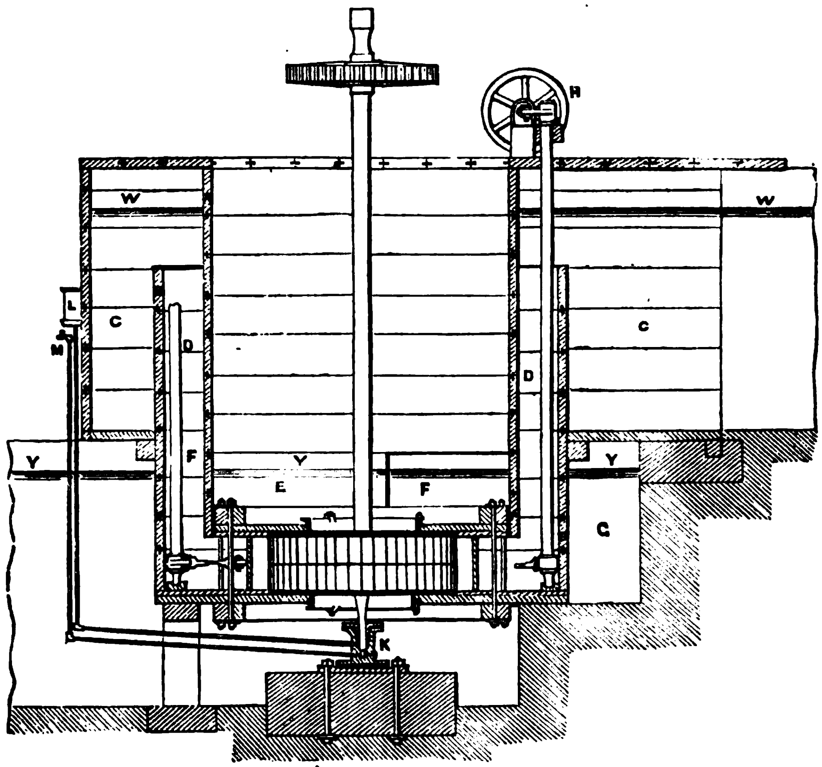

already described, but it differs in the material of which the case is constructed, and in the manner in which the water is led to the guide-blade chamber. In this the case is almost entirely of wood: and, for simplicity, the drawings represent it as if made of wood alone, though in reality, to suit the other arrangements of the mill, brickwork in certain parts was substituted for the wood. The water flows with a free upper surface, W W, into this wooden case, which consists chiefly of two wooden tanks, A A and B B, one within the other. The water-wheel chamber and the guide-blade chamber are situated in the open space between the bottom of the outer and that of the inner tank, and will be readily distinguished by reference to the figures. The water of the head-race, having been led all round the outer tank in the space C C, flows inwards over its edge, and passes downwards by the space D D, between the sides of the two tanks. It then passes through the guide-blade chamber and the water-wheel, just in the same way as was explained in respect to the high-pressure vortex already described; and in this one likewise it makes its exit by two central orifices, the one discharging upwards and the other downwards. The part of the water which passes downwards flows away at once to the tail-race, and that which passes upwards into the space E within the innermost tank, finds a free escape to the tail-race through boxes and other channels, F and G, provided for that purpose. The wheel is completely submerged under the surface of the water in the tail-race, which is represented at its ordinary level at Y Y Y, Fig. 4073, although in floods it may rise to a much greater height. The power of the wheel is regulated in a similar way to that already described in reference to the high-pressure vortex. In this case, however, as will be seen by the figures, the guide-blades are not linked together, but each is provided with a hand-wheel H, by which motion is communicated to itself alone.

In this vortex, the fall being taken at 7 ft., the calculated quantity of water admitted at the standard opening of the guide-blades is 2460 cub. ft. a minute. Then, the efficiency of the wheel being taken at 75 per cent., its power will be 24 horse-power. Also the speed at which the wheel is calculated to revolve is 48 revolutions a minute.

In connection with the pivot of this wheel, arrangements are made which provide for the perfect lubrication of the rubbing surfaces with clean oil. The lower end of the upright revolving shaft enters a stationary pivot-box K, through an opening made oil-tight by hemp and leather packing.

Within the box there is a small stationary steel plate on which the shaft revolves. Within the box, also, there are two oil-chambers, one situated above and round the rubbing surface of this

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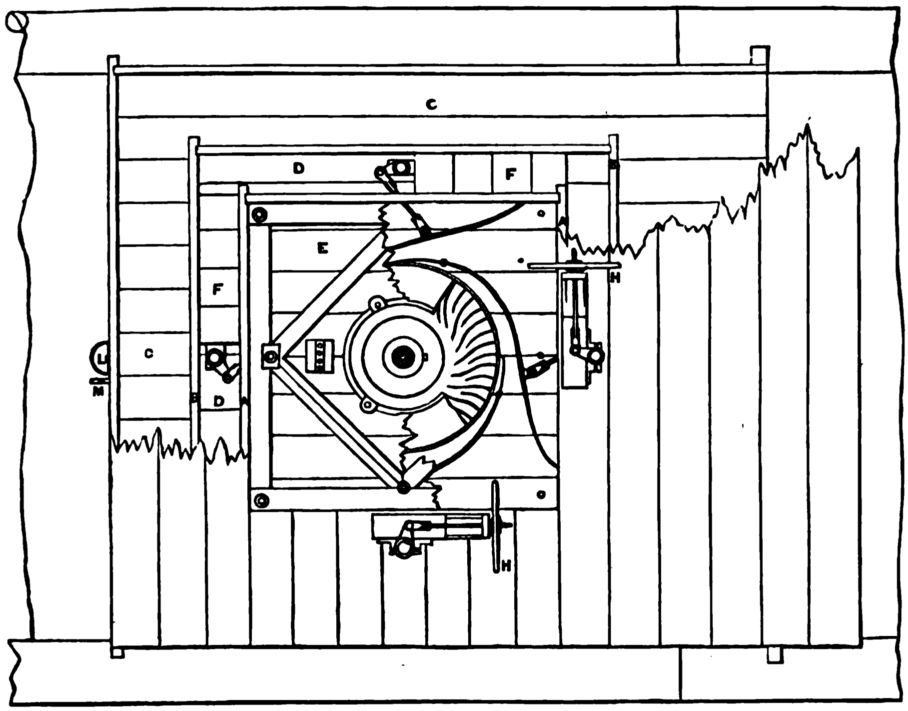
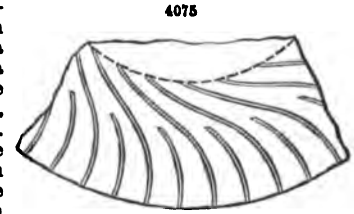


plate, and the other underneath the plate. A constant circulation of the oil is maintained by centrifugal force, which causes it to pass from the lower chamber upwards through a central orifice in the steel plate, then outwards through a radial groove in the bottom of the revolving shaft to the upper chamber, then downwards back to the lower chamber, by one or more grooves at the circumference of the steel plate. The purpose intended to be served by the provision of the lower chamber combined with the passages for the circulation of the oil, is to permit the oil, while passing through the lower chamber, to deposit any grit or any worn metal which it may contain, so that it may be maintained clean and may be washed over the upper surface of the steel plate at every revolution of the radial groove in the bottom of the shaft. A pipe leading from an oil-cistern L, in an accessible situation, conducts oil to the upper chamber of the pivot-box; and another pipe leaves the lower chamber, and terminates, at its upper end, in a stop-cock M. This arrangement allows a flow of oil to be obtained at pleasure from the cistern, down by the one pipe, then through the pivot-box, and then up by the other pipe, and out by the cock. Thus, if any stoppage were to occur in the pipes, it could be at once detected; or if water or air were contained in the pivot-box after the first erection, or at any other time, the water could be removed by the pipe leading to the stop-cock, or the air would of itself escape by the pipe leading to the cistern, which, as well as the other pipe, has a continuous ascent from the pivot-box. Certainty may consequently be attained that the pivot really works in clean oil.

4075



Part of the wheel, Fig. 4074, drawn on a larger scale to show the curvature of the vanes more correctly.

The inventor, J. Thomson, was led to adopt the pivot-box closed round the shaft with oil-tight stuffing, from having learnt of that arrangement having been successfully employed by Köchlin, an engineer of Mühlhausen. As to the other parts of the arrangements just described, he believes the settling chamber with the circulation of oil to be new, and he regards this part of the arrangements as being useful also for pivots working not under water. In respect to the materials selected for the rubbing parts, however, he thinks it necessary to state that some doubts have arisen as to the suitableness of wrought iron to work on steel even when perfectly lubricated; and he would therefore recommend that a small piece of brass should be fixed into the bottom of the shaft, all parts being made to work in the manner already explained.

The two examples which have now been described of vortex water-wheels adapted for very distinct circumstances, will serve to indicate the principal features in the structural arrangements

of these machines in general. Respecting their principles of action, some further explanations will next be given. In these machines the velocity of the circumference is made the same as the velocity of the entering water, and thus there is no impact between the water and the wheel; but, on the contrary, the water enters the radiating conduits of the wheel gently, that is to say, with scarcely any motion in relation to their mouths. In order to attain the equalization of these velocities, it is necessary that the circumference of the wheel should move with the velocity which a heavy body would attain in falling through a vertical space equal to half the vertical fall of the water, or in other words, with the velocity *due* to half the fall; and that the orifices through which the water is injected into the wheel-chamber should be conjointly of such area that when all the water required is flowing through them, it also may have a velocity due to half the fall. Thus one-half only of the fall is employed in producing velocity in the water; and therefore the other half still remains acting on the water within the wheel-chamber at the circumference of the wheel in the condition of fluid pressure. Now, with the velocity already assigned to the wheel, it is found that this fluid pressure is exactly that which is requisite to overcome the centrifugal force of the water in the wheel, and to bring the water to a state of rest at its exit, the mechanical work due to both halves of the fall being transferred to the wheel during the combined action of the moving water and the moving wheel. In the foregoing statements, the effects of fluid friction, and of some other modifying influences, are, for simplicity, left out of consideration; but in the practical application of the principles, the skill and judgment of the designer must be exercised in taking all such elements as far as possible into account.

In respect to the numerous modifications of construction and arrangement which are admissible in the vortex, while the leading principles of action are retained, it may be sufficient here merely to advert—first, to the use of straight instead of curved radiating passages in the wheel; secondly, to the employment, for simplicity, of invariable entrance orifices, or of fixed instead of movable guide-blades; and lastly, to the placing of the wheel at any height, less than about 30 ft. above the water in the tail-race, combined with the employment of suction-pipes descending from the central discharge orifices, and terminating in the water of the tail-race, so as to render available the part of the fall below the wheel.

In relation to the action of turbines in general, the chief and most commonly recognized conditions, of which the accomplishment is to be aimed at, are that the water should flow through the whole machine with the least possible resistance, and that it should enter the moving wheel without shock, and be discharged from it with only a very inconsiderable velocity. The vortex is in a remarkable degree adapted for the fulfilment of these conditions. The water moving centripetally (instead of centrifugally, which is more usual in turbines) enters at the period of its greatest velocity (that is, just after passing the injection orifices) into the most rapidly moving part of the wheel, the circumference; and, at the period when it ought to be as far as possible deprived of velocity, it passes away by the central part of the wheel, the part which has the least motion. Thus in each case, that of the entrance and that of the discharge, there is an accordance between the velocities of the moving mechanism and the proper velocities of the water.

The principle of injection from without inwards, adopted in the vortex, affords another important advantage in comparison with turbines having the contrary motion of the water; as it allows ample room, in the space outside of the wheel, for large and well-formed injection channels, in which the water can be made very gradually and regularly to converge to the most contracted parts, where it is to have its greatest velocity. It is as a concomitant also of the same principle that the very simple and advantageous mode of regulating the power of the wheel by the movable guide-blades already described can be introduced. This mode, it is to be observed, while giving great variation to the areas of the entrance orifices, retains at all times very suitable forms for the converging water channels.

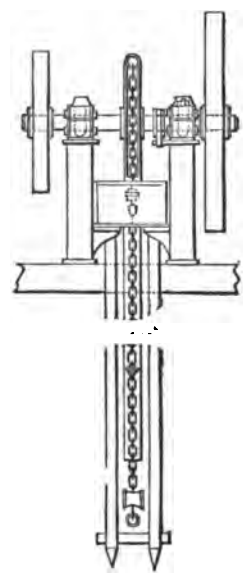
Another adaptation in the vortex is to be remarked as being highly beneficial, that namely according to which, by the balancing of the contrary fluid pressures due to half the head of water and to the centrifugal force of the water in the wheel, combined with the pressure due to the ejection of the water backwards from the inner ends of the vanes of the wheel when they are curved, only one-half of the work due to the fall is spent in communicating *vis viva* to the water, to be afterwards taken from it during its passage through the wheel; the remainder of the work being communicated through the fluid pressure to the wheel, without any intermediate generation of *vis viva*. Thus the velocity of the water, where it moves fastest in the machine, is kept comparatively low; not exceeding that due to half the height of the fall, while in other turbines the water usually requires to act at much higher velocities. In many of them it attains at two successive times the velocity due to the whole fall. The much smaller amount of action, or agitation, with which the water in the vortex performs its work, causes a material saving of power by diminishing the loss necessarily occasioned by fluid friction.

This description is the one given by the inventor. We referred, p. 1923, to the turbine water-wheel of J. Thomson as that of Williamson Brothers, who are the manufacturers of it. The opinion expressed, p. 1923, is that of the experienced hydraulic engineers MM. L. Vigreux and A. Raux; see p. 140, vol. iii., of E. Lacroix's work on the Paris Exhibition of 1867. Many engineers as well as the manufacturers of this vortex water-wheel, hold a different opinion to that of MM. Vigreux and Raux.

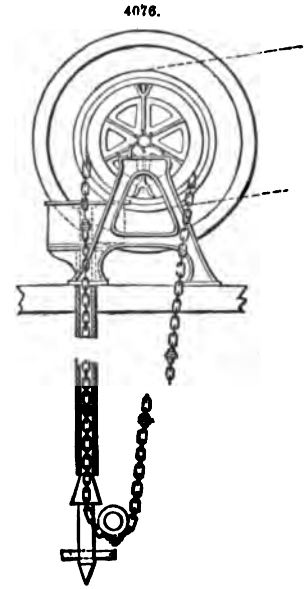
Chain-pumps.—Bastier's chain-pump, Figs. 4076, 4077, is very effective; 80 per cent. of the units of work applied are utilized. A vertical iron pipe descends to a little below the level of the water; an endless iron chain, carrying buckets at equal distances, works up the pipe and winds round a wheel erected on the top of the well. The buckets are provided with a pump-gear, consisting of a leathern washer enclosed between two iron discs; the diameter of the washer is a little less than that of the pipe, so as to leave a little play. The lower part of the pipe only is bored to the diameter of the washers, which at this point act as pistons. The object of this arrangement is to diminish

the loss of water without causing much friction. The tube terminates upwards in a trough from which the water flows away. The motive pulley, upon which the chain should arrive tangentially, is scored to receive the links of the chain. The circumference of this pulley should contain an exact number of times the distance between two washers, and hollows should be cut in the groove to receive these washer-plugs; this prevents the chain from slipping. The chain is sufficiently weighty to require only a small guide-pulley at the bottom of the pipe.

4077.



4076.



The velocity of rotation of the wheel is at least 30 or 40 revolutions a minute, and may go up to 100, which corresponds to a velocity in the chain of $1^{m}\cdot 50$ to 5 mètres a second. Whatever the inventor may say, however, we think that a high velocity is unfavourable to the percentage of work, first because the friction of the water against the sides of the pipe and the plugs increases, and second, because the water arrives at the top with a useless velocity.

This machine is employed in mines, and with very good results. Theoretically it is adaptable to any height; but if the depth is very great, the useful effect is certainly diminished. The constructor guarantees from 80 to 90 per cent. of work, but as we have not had an opportunity of verifying these figures, we give them under reserve.

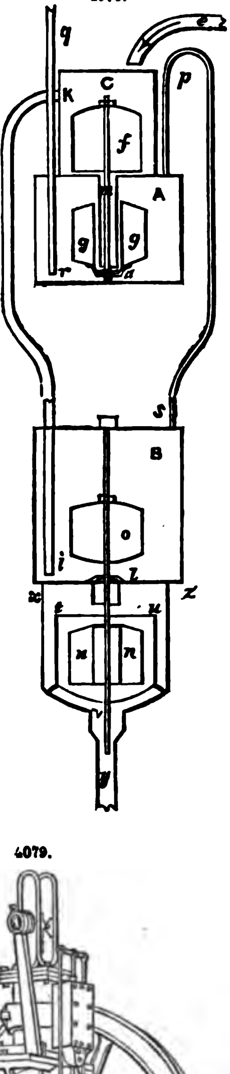
M. Durozoi's Hydraulic Propeller.—This is a simple and rustic machine, and in certain cases it may be advantageously substituted for a pump. The ascension-pipe terminates downwards in a fixed cylinder of a considerable diameter, which is sunk beneath the water. A kind of bucket fixed to movable vertical rods outside the cylinder, is moved up and down by means of these rods and a hand-lever fixed on the top of the well. At each stroke the bucket fills itself, and lifts the column of water in the ascension-pipe; as this column cannot fall back into the well, a portion of it is ejected above. The apparatus may be with single or double action, and the arrangement of the levers may be varied at will. It is applicable to any depth, since there is no suction, but it is obvious that a great length in the transmission-rods is objectionable. It is easily fixed, and rarely gets out of order. It may be used to raise dirty water, or to irrigate with liquid manures; or it may be used in tan-yards or in gas-houses, to raise the coal-tar.

Caligny's Conical Pump, without Piston or Valve.—M. Coligny has made many experiments and formed many theories respecting certain oscillating motions of water in pipes; and he has invented a great number of machines for utilizing a fall of water to raise water. We will not describe these machines here, for we do not consider them of very much value; we will merely mention one which he calls a pistonless and valveless pump. This is a simple pipe of iron or zinc, 4 mètres in length, cylindrical throughout the upper half of its length, and conical below, the diameters being $0^{m}\cdot 13$ in the cylindrical portion, and $0^{m}\cdot 36$ at the lower base of the cone. An alternating vertical motion given to this apparatus produces in the water in which it plunges certain oscillations which cause it to ascend to the top of the pipe, where it may be received. Considerable practice is necessary to arrive at this result. It would occupy too much of our space to explain the theory of this instrument.

Champsaur's Autodynamic Elevator.—This is in reality a Héron fountain, rendered self-acting by an ingenious arrangement of floats and valves. The water enters through a pipe *e*, Fig. 4078, into a receptacle C, and passes thence through the pipe *m* into a closed receptacle A. A float *g*, placed in this vessel, and bearing a valve *d*, is weighted so as to have a weight equal to the weight of the water which it displaces; consequently it loses its weight, but does not change its position. The level ascends into the vessel C, up to the float *f*, which, being connected with the float *g*, raises the latter, and closes the valve *d*. When the water has reached the height K, it flows off through the pipe K *i*, which takes it into a second closed receptacle B, placed at the level obtainable. As the receptacle B fills, the air which it contains is compressed, and through the tube *s p* forces the water remaining in A up the ascension-pipe *r q*. When the level of the water has reached *r*, the compressed air escapes through the same ascension-pipe, the atmospheric pressure is restored in both receptacles, the float *g* drops and opens the valve *d*, and the water begins again to fill the receptacle A. During this time the receptacle B must be emptied; for this purpose there is attached to the rod of the discharge-valve *l* a float *o*, the ascending power of which is sufficient to open this valve when the pressure upon it does not exceed that of a column of water of the height of the receptacle. So long as the air is compressed by the column of water K *i*, the valve *l* remains therefore closed; but as soon as the atmospheric pressure is

restored, the float *o* rises, and the water flows off. The valve *l* must remain open until the emptying is complete, and to obtain this result the water is received into a system of concentric vessels *t u*, *x z*, terminating in a discharge-pipe *y*. The inner vessel has an orifice *v*, too small for the quantity of water that issues; the water then lifts the float *n*, which by its rod holds the valve open, and the latter does not close till the vessel B is quite empty.

4078.



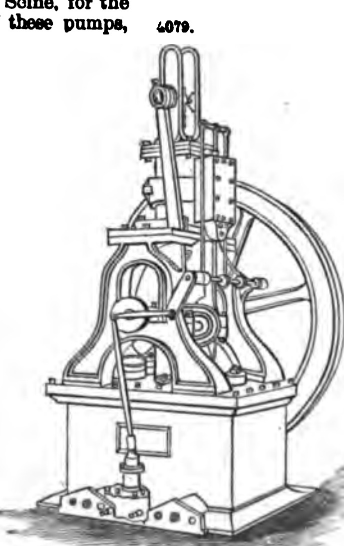
The water is thus raised in an intermittent manner in the ascension-pipe *r q*, if the various parts of the apparatus have suitable relative dimensions. The limit of the useful effect of this machine may be easily determined. Let Q be the quantity of water that arrives through the pipe *e*; H the height of the level of the vessel C above the level of the receptacle B; H′ the height of ascension above the level of the receptacle A; V and V′ the disposable volumes of the two receptacles B and A. It is evident that H′ cannot exceed H, and that it is even a little less. Moreover, by applying Boyle's law, we have $\frac{V}{V'} = \frac{H' + 10^{m}\cdot 33}{H + 10^{m}\cdot 33}$. If H′ = H, we have V = V′; but H′ being less than H, V is a little less than V′. V is the volume of water raised, V′ is the volume of water expended, and their sum is equal to Q; therefore the quantity of water raised is always a little less than the half of quantity of water made use of. As to the dynamic work of the apparatus, it is certainly very great, the loss of height of water being only equal to that of the vessel C, and the resistances being small, for they are reduced to the resistance of the valves and the friction of the water.

Though the autodynamic elevator requires a long description, it is very simple, and when clear water has to be raised, it needs but little attention. It may be of service in certain cases, such, for instance, as distributing the water supplied to a house; the level reaching about the middle of the house, about half of the quantity allowed may be raised to the upper stories, the second half, in this case, not being lost, since it may be used on the ground floor. This has been successfully done at Marseilles. The arrangement of the apparatus may be varied with circumstances, and the inventor says that with a slight modification it may be employed to raise other liquids without their becoming mixed with the motive water.

Pumps proper.—Under this head we shall include all piston-pumps with an alternating motion, with single or double action, whether worked by hand or by an inanimate motor. Reserving for a later page fire-engines, which may be grouped together, and the kind of pumps called unlimited, we will examine a number of models by the principal makers, without confining ourselves to any particular order, a simple classification being very difficult.

Common Pumps.—Scott's Steam-pumps.—Thomas Scott, of Rouen, erected two of his steam-pumps upon the banks of the Seine, for the service of the International Exhibition of 1867. Each of these pumps, or rather pumping machines, consisted of two vertical pumps with a plunger-piston, the rods of which were connected with a beam, and moved in contrary directions. One of Woolf's two-cylinder engines acted upon one end of the beam, the other carried the connecting rod of a fly-wheel common to both machines. The support of the beam was a hollow cast-iron column, which served at the same time as an air-reservoir.

4079.



This kind of motor is well adapted, from its slow and regular motion, to the working of large pumps. It has an elegant appearance, and its motion is majestic, as the motion of this form of engine should be: but we are not at all sure that its action would continue satisfactory for any length of time. Such constructions must be very accurately made, and carefully put together.

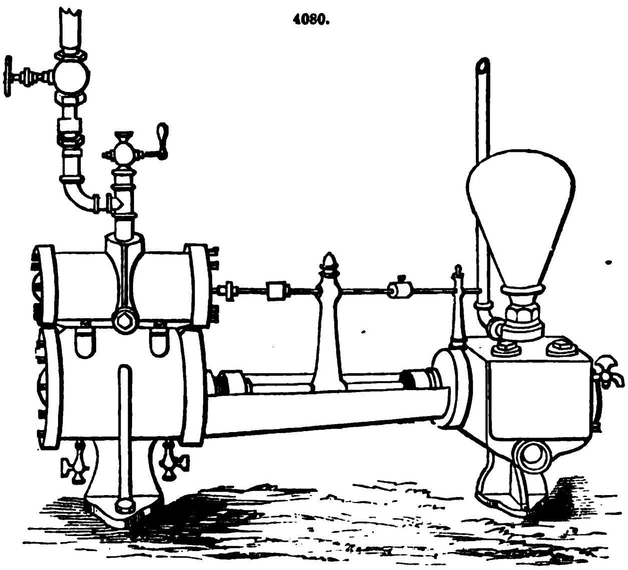
Carrett, Marshall, and Co.'s Steam-pumps, Fig. 4079.—These machines consist of a steam-engine and a lift and force pump, with a plunger-piston, upon one frame. The kind represented in the figure, which is capable of raising 10 cub. mètres an hour to a height of 30 mètres, consists of a vertical steam-cylinder fixed in the upper part of the frame, and driving a shaft carrying a fly-wheel, which, by means of a crank, drives the plunger-piston. The frame is erected upon the water-cistern, which contains reservoirs of air for the suction and the forcing. If the steam-engine is supplied by a special boiler, a small force-pump may be added (shown in the fore part of the figure) for the service of the boiler. All the parts are put together so as to occupy a small space on the ground.

In another and smaller kind the steam-piston and the plunger have a rod in common, only

interrupted by a frame for the place of the crank which drives the fly-wheel; the reservoirs of air are in the columns of the frame. These arrangements are adapted only to cases where the suction does not exceed 7 or 8 mètres. In the case of a greater height, the motor must be separated from the pump by lowering the latter into the well.

Earle's Steam-pump.—Earle, of Springfield, Massachusetts, has produced a pump, Fig. 4080, which is interesting from its thoroughly American simplicity and originality. The steam-piston and the plunger, both horizontal, are connected by a rod which is common to both. The slide-valve consists of a simple cast-iron cylinder, perfectly balanced, which lets the steam alternately upon the two faces of the piston. The piston-rod is provided with a vertical piece, which, at the end of each stroke, strikes against cleats upon the slide-valve rod, the intermittent motion of which is thus very simply commanded by the motor.

4080.

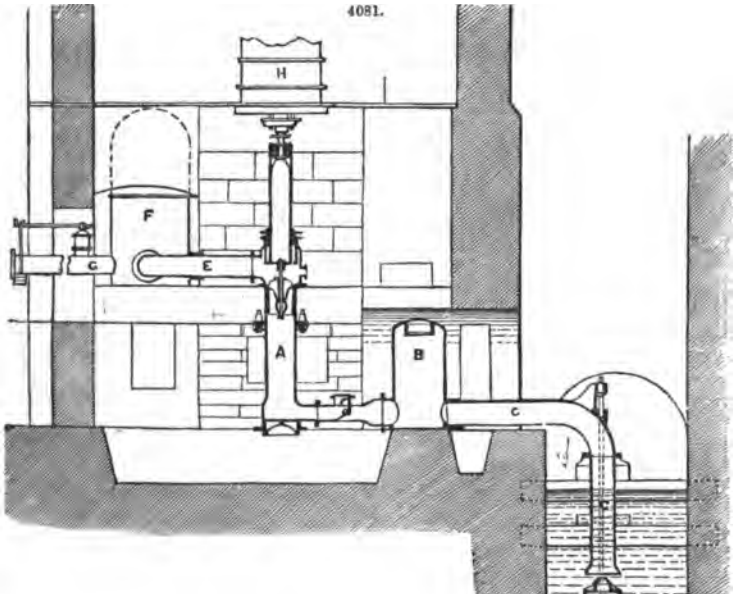


The particular arrangement of the slide-valve obviates the necessity for a fly-wheel or any revolving part, there being no dead-points; the engine is set in motion by simply turning on the steam. We may add that the various parts are arranged so as to be easily inspected, and the construction of the water-box allows of the valves being changed at pleasure; the pistons have a metallic packing, and there is a reservoir of air on the top of the water-cylinder, designed to regulate the ascension.

This pump is certainly a very remarkable one. Simplicity of construction, lightness, and consequently lowness of price, easy motion, suitability to a variable motion (a slow motion, however, gives the highest percentage of work); such are the principal advantages which recommend it to the attention of engineers.

We may here mention a ship's pump, though this belongs rather to marine engines, exhibited in the International Exhibition of 1867, and there called a steam-pump of the Forges et Chantiers

4081.



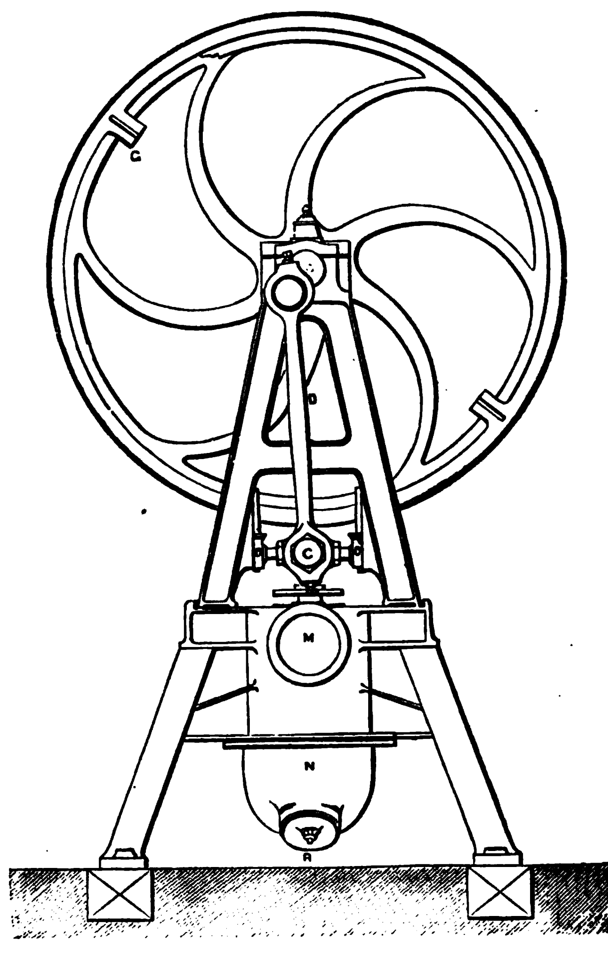
de l'Océan. The arrangement of this pump, as in the case of the foregoing, obviates the necessity for a fly-wheel, or any other revolving part; hence great simplicity of construction and an inconsiderable weight. Two horizontal steam-cylinders act directly upon two water-cylinders, the pistons being connected by rods common to both. One of the steam-pistons is always in the middle of its stroke when the other is at the end of its stroke; hence the two pistons command reciprocally their slide-valves without the medium of eccentrics or any similar contrivances. Besides this a certain regularity of motion is obtained. With a velocity of 100 strokes a minute this engine will raise 600 cub. mètres of water an hour to a height of 15 mètres.

Farcot's Steam-pumps.—To show the nature of these pumps, we will describe one used at the water-works at Angers, Fig. 4081. It is a vertical pump, the piston of which is connected directly with the piston of a steam-cylinder H above. The steam-engine is not shown in the figure, but it is of 45 nominal horse-power, and, at a speed of 16 revolutions a minute, gives an effective work in water raised of 39 horse-power.

The pump A is of single action in the suction and of double action in the forcing. This is effected by means of a double piston with a single rod; the lower end is a hollow, clack-valve piston (diameter $0^{m}\cdot48$), and the upper end, a plunger-piston, of a smaller diameter ($0^{m}\cdot35$). The common stroke is of $1^{m}\cdot20$. During the descent the water passes through the lower piston and is forced by the plunger; during the ascent, there takes place a sucking and a forcing of a volume of water depending on the difference of surface of the two pistons. The proportion between these two surfaces is calculated, regard being had to the heights of sucking and forcing, so as to produce a work about equal to the ascending and descending. The other interesting parts of the machine are: a reservoir of air B placed upon the suction-pipe C; a valve D which may be shut at pleasure; a reservoir of air F upon the forcing pipe E, with a level indicator and a contrivance for supplying the reservoir with air; and a safety-valve G with an alarm whistle.

Another system of Farcot's pumps is shown in Figs. 4082, 4083. This was erected a few years ago to supply water to the town of Lisbon. It includes two barrels or pump-chambers A, A', $0^{m}\cdot45$ in diameter, joined at the base by the vessel N. The two pistons B. B', have a stroke of $0^{m}\cdot15$; their rods are connected by a cross-piece C, connected with the cranks upon the shaft of the driving wheel G by two connecting rods D, D'. Both pistons move together and in the same direction; they are provided with similar clack-valves, but opening inversely. During the ascending motion the piston B' sucks from the tank N, and forces the water above it into the air-reservoir P, and from there to the works; at the same time the piston B, having its valves open, allows the water coming through M to pass. During the descending stroke, the piston B sucks through the pipe M and forces the water beneath B', which allows it to pass. This arrangement possesses the advan'age of making the water flow always in the same direction, which is not the case with common pumps. The principle is the same as that of Stolz's twin pump, of which we will speak later, with this difference, that the pistons move simultaneously. There are no other valves than those of the pistons; these are very large, to lessen the resistance to the passage of the water. They consist of three parallel series of inclined traps, Fig. 4084, formed of metallic plates p, lined with leather m on the closing side, and with india-rubber n acting as a spring on the other side; the course of the traps is limited by the stops q. The piston B' is

4082.

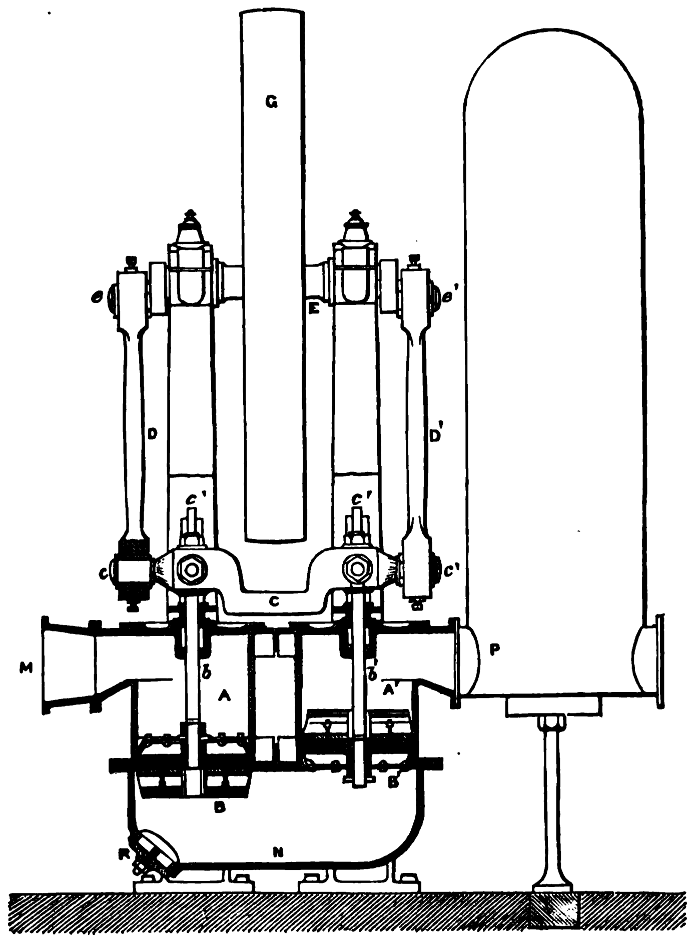


in every respect similar to B, but reversed.

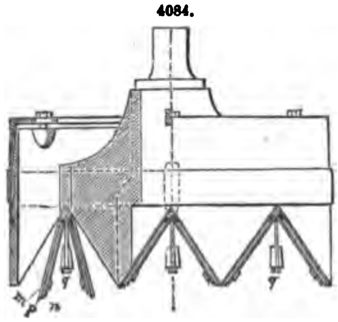
The effective work of this pump is great. For rates of speed varying from 25 to 60 revolutions a minute, experiments have shown a mean of 0·60 of work. The percentage increased with the height, and reached, for a height of 13 mètres, 0·74 for 45 revolutions, and 0·70 for 60 revolutions. The waste is from 2 to 10 per cent. It will be seen that the number of strokes may be pretty great, which renders a light motor sufficient; but the maker has been careful to choose a small stroke in order not to increase the velocity of the water at the expense of the useful effect.

As a specimen of another kind, we give in Fig. 4085 a horizontal double-action pump, the piston of which is solid, but with inner gear. The cylinder, the clack-boxes, and the air-reservoir placed on the top, form a single body, of cast iron, and very compact; the four valves may be easily inspected, and the form of all the parts is such that the water is not compelled to flow round sharp angles, a condition which lessens the resistance.

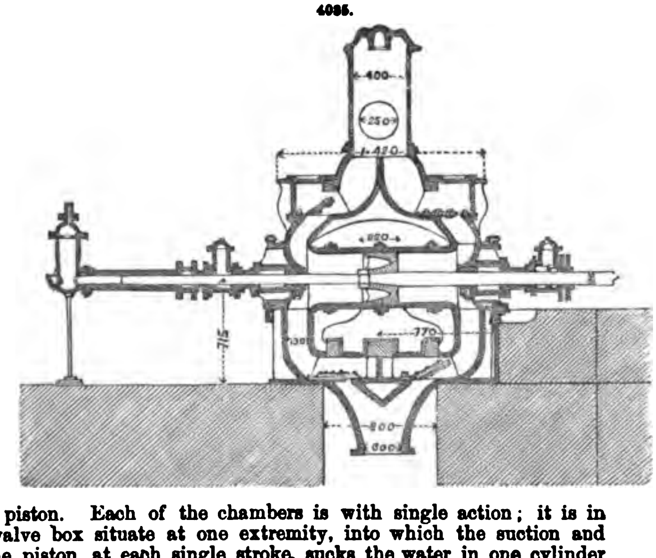
4083.



4084.



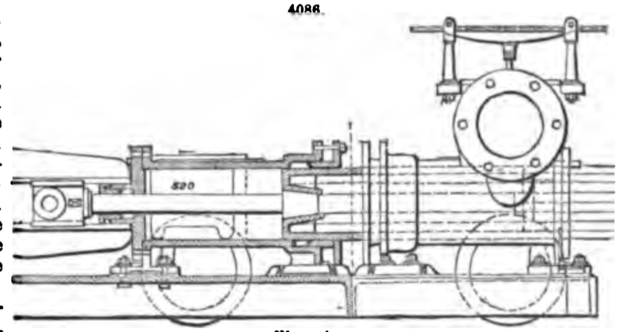
4085.



Girard's Horizontal Pump, Figs. 4086 to 4088.—This system of pump, which is designed to be worked by an inanimate motor, comprises two horizontal pump-chambers with a single piston. Each of the chambers is with single action; it is in communication with a double valve box situate at one extremity, into which the suction and delivery pipes open, so that the piston, at each single stroke, sucks the water in one cylinder and forces it in the other. The valves are well guided in their upward course, and they fall

by their own weight, assisted by the action of a spring above, the flection of which may be regulated at pleasure. The suction as well as the delivery tubes are brought together upon the same conduit. The piston is a hollow cast-iron, or better bronze cylinder, traversed from end to end by the rod, and having no external projection; it has a diameter of $0^{m}\cdot29$ and a stroke of $0^{m}\cdot52$. The gear or leathering is on the outside, which renders its inspection and repair easy. The whole is erected upon a cast-iron stand, on which are the piston-rod guides and the plummer-blocks of the driving shaft. This part is not shown in the figure. The design and the construction of this pump are equally good.

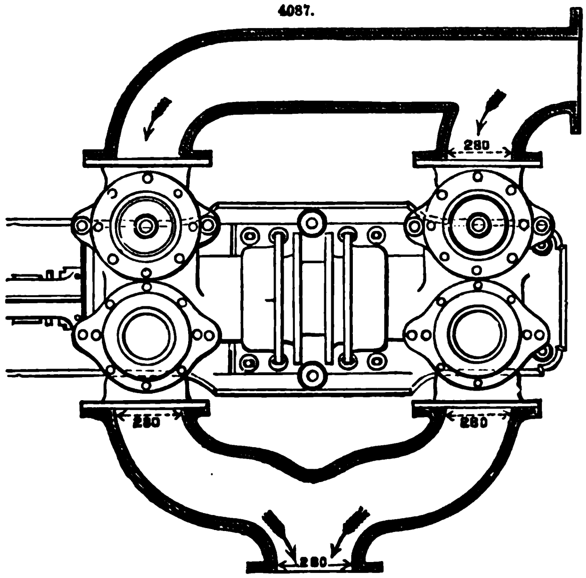
4086.



Elevation.

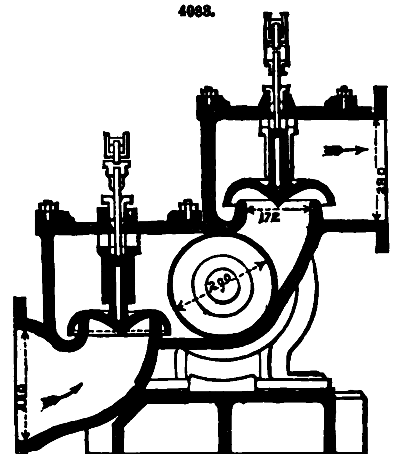
Letestu's Pumps.—M. Letestu's pumps are well known,

4087.



Plan.

4088.



Section of clack-box.

and have been used to empty docks, among other applications. Their peculiarity is in the form of the piston, which, instead of terminating in plane faces, is composed of a copper cone pierced with holes, and covered with a piece of prepared leather rolled back upon itself and replacing the clack-valve. This leather opens during the descent of the piston, and allows the water to pass through the holes, and closes, on the contrary, as the piston ascends. The pump is thus a single-action, suction, and lift pump; the stream which it supplies becomes continuous by employing two barrels, or a reservoir at the top.

Experiments made at the Conservatoire des Arts et Métiers, gave 0·48 to 0·51 as the mean percentage of work; it reached 0·56 at low rates of speed; long strokes, with an equal velocity, are favourable to the useful effect. The waste, or quantity lost, is from 5 to 7 per cent. of the volume generated by the piston.

These pumps possess advantages in many cases. The piston is less liable to choke than the common pistons when thick, muddy water has to be raised; but the foot-valves at the bottom of the cylinder, possessing no peculiar feature, may act badly and stop the working of the pump. The pistons seldom get out of repair, and when they do, the repairs are easily effected. This, with the little difficulty experienced in fixing them, explains the very general adoption of these pumps. The arrangements for driving them necessarily vary with the use they are to be put to, and also with their power. The largest exhibited in the Paris Exhibition was a double, vertical, chambered pump, the chambers $0^{m}\cdot60$ in diameter. The pistons were driven by cranks fixed upon two toothed wheels of the same diameter, driven by a single pinion. The motor was a steam-engine; a fly-wheel upon the shaft of the pinion regulated the motion, and a reservoir of air in the middle keeps up a continuous flow. The quantity of water discharged was 400 cub. mètres an hour.

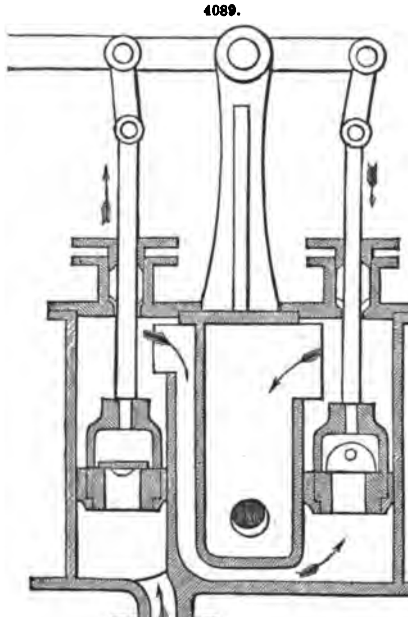
Nillus's Pumps.—This system, the invention of MM. Nillus, of Havre, is commonly known under the name of the *Priest's pump.* The piston is replaced by a piece of flexible leather fixed by its edges to the sides of the chamber (enlarged at this point), and having in the middle a button, to

which a rod and a valve are attached. By communicating a reciprocating motion to the rod, the valve opens and shuts as the leather takes alternately a concave or a convex form, and the water is sucked up and forced out accordingly. These pumps possess the advantage of working well in thick, muddy waters. The useful effect, notwithstanding the diminution of friction due to the absence of a piston, does not exceed that of good common pumps. Experiments made with a two-chambered model, in which the leather was $0^{m}\cdot 6$ in diameter and the valve $0^{m}\cdot 15$, showed a mean work of 0·50. This percentage decreased as the speed increased, which is usually the case.

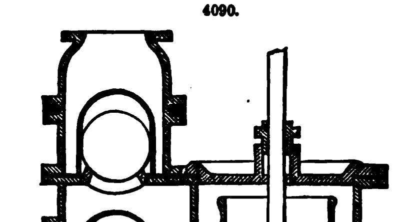
Thirion's Pump.—This pump consists of two pump-chambers with plunger-pistons, the rods of which are actuated by a beam placed above, and supported by the air-reservoir. The beam is not symmetrical; one end is carried out and jointed to a connecting rod, which connects it with a fly-wheel that receives its motion from a portable engine. Gearing is made use of to diminish the speed. The use of a beam that does not receive directly the force from the steam-piston seems to us objectionable; it uselessly increases the weight of the machine, the various parts are not sufficiently compact, which renders a large frame necessary, and the fly-wheel is placed far from the resistance, which is an irrational arrangement.

Henry and Peyrolles's Pumps.—Henry and Peyrolles, successors to M. Stolz, of Paris, have made, in their *twin pumps*, Fig. 4089, a modification of the essential parts of a pump. This variety has two cylinders, and the pistons, which are hollow and provided with valves, move in contrary directions. The middle chamber, through which the water is forced, is in communication with the upper face of only one of the pistons. It will be seen, from an inspection of the figure, that the water, sucked up by the left piston, passes through it and then flows beneath the right piston, which forces it up into the middle chamber. Thus the water always flows in the same direction, and the resistances due to a change of direction avoided. It is true that this advantage is lessened by the fact that the water has a longer circuit to make, by which the friction is increased; but it may be driven at a greater speed than the common systems. We do not know of any experiments made to ascertain the percentage of work obtained from this pump. We will speak of the rotative pumps of this maker farther on.

4089.



4090.



The Castraise Pumps, constructed by MM. Schabaver and Foures, of Castres, Fig. 4090.—These are sucking and forcing, double-action pumps, with a single pump-chamber. The piston is leathered, but has no valves; the pump-chamber, which is either vertical or horizontal, is enclosed in a tank divided by a diaphragm perpendicular to the axis of the piston. The valves, four in number, are hollow india-rubber balls, weighted in the centre with small shot. They are arranged in pairs in two lateral boxes, a section of which is shown in the figure, the lower valve serving for the sucking and the upper for the forcing. Each half of the water-box enclosing the pump-chamber is in constant communication with the interval between the two valves of a box. In the figure the lower part of the tank corresponds with the valves represented. While the piston is sucking through one box it is forcing through the other, which is the case with all double-action pumps. The peculiarity of the Castraise pump is the use of the water-tank spoken of above, the effect of which is to render the volume of water contained in the pump much larger than the volume of the cylinder; the consequence of this is that a portion of the water acted on by suction traverses the valve-chambers only, without passing through the pump-chamber, the piston being, so to speak, always in contact with the same water. This arrangement enables the pump to work in muddy water by placing the piston beyond the reach of injury from the passage of gravel, and so on.

Experiments have given 0·56 as the mean percentage of work, the highest, for a low rate of speed, being 0·66. The waste or loss of water was from 7 to 10 per cent. The action of these pumps, the form and dimensions of which vary with their application, is very satisfactory, and their cost is not great, in spite of their relatively great weight. The makers have added to their latest models an air-reservoir, from which they expect good results.

Perreaux's Pump.—The essential character of Perreaux's pump consists in the use of india-rubber valves, cylindrical at the base and flat at the top, which gives them the form of the mouthpiece of a clarionet. Like this latter, they terminate in two lips which, under the influence of the pressures resulting from the rising and falling of the piston, open or close through the elasticity of the material. One advantage of this elasticity is that the solid matters brought in with the water may pass through without causing injury. The retaining valve is placed at the bottom of the cylinder, whilst the other, suitably extended in a cylindrical form at its base, forms a piston. The india-rubber is stiffened with ribs of the same material. The pump-chamber is of copper, and may be enclosed in wood. The upper part, which is closed, serves as an air-reservoir if the pump is simply a suction-pump; if it is to be forcing as well, a small copper cylinder placed at the side, and also provided with an india-rubber valve, forms the air-reservoir. The various parts are easily taken to pieces. These very simple constructions may be made of any form; they are of great service for agricultural purposes, and whenever it is required to raise water loaded with sand.

Motte's Bellows Pump.—The necessity of keeping the leathering in a good condition in piston-pumps has led to the adoption, for hydraulic purposes, of the principle, familiar to all, of a pair of bellows. Motte's pumps, which are frequently employed to clear the water from excavations, consist of two iron plates put together with leathern sides in exactly the same way as a common pair of bellows. They are worked by means of a beam. We have no numerical data relative to the useful effect, but there must be a considerable loss of power due to the dead-spaces in which the air is compressed and expanded uselessly at each stroke. These machines are well made, and they work very smoothly.

Armandies' Balance-beam Pump.—This pump is similar in principle to the one described above. Two pieces of wood or plate iron, at an obtuse angle with each other and provided with valves, are fixed to a kind of vertical iron beam oscillating about a lower horizontal shaft. A lever attached to the beam applies alternately the plates upon the openings of a cast-iron box at the end of the suction-pipe. The plates and the horizontal shaft are wholly under water; this prevents the heating of the parts and renders greasing unnecessary. Besides this, the valves being always visible, may be easily cleared by the hand when impure water is being raised. This pump is simple and applicable to agricultural uses, or it may be employed to clear away small bodies of water. It must be remarked, however, that it acts only by suction, and cannot be made to force, at least without introducing modifications which would destroy its rustic character.

4091.

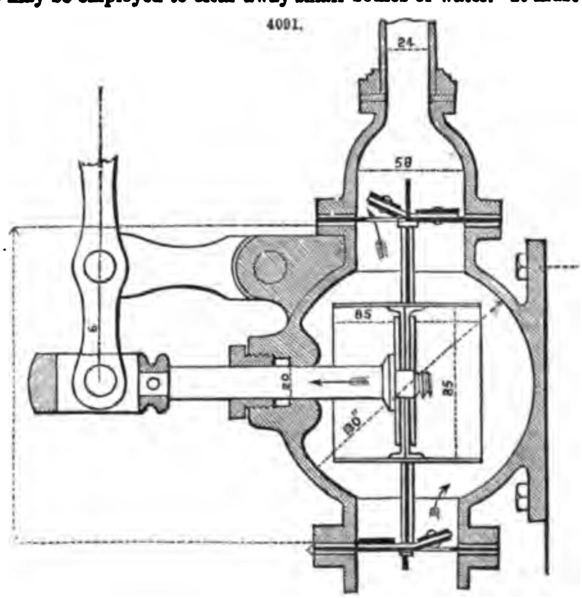


Fig. 4091 represents an excellent little pump for agricultural purposes. It is a Champonnois pump, and its peculiarity consists in its being double-actioned with a single pump-chamber.

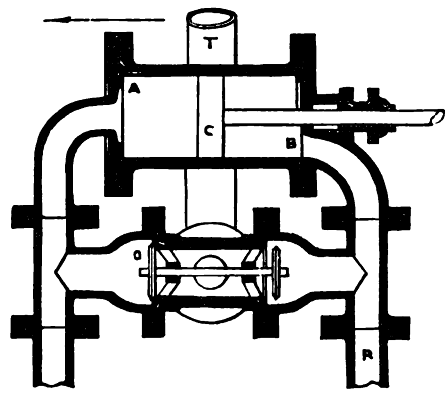
Unlimited Pumps.—The name unlimited pumps has of late years been applied to a great number of apparatus for raising water from a depth greater than 25 or 30 ft., beyond which point suction ceases. We shall not include under this head the common plan of putting a suction-pump down a well at a sufficient level, and working it by means of rods or other contrivances. This plan is constantly made use of in deep wells, and when the depth is very great, as in the case of mines, a number of pumps are placed one above another at different levels and worked by a main rod.

Prudhomme's Pumps.—M. Prudhomme, the first to adopt the name unlimited, invented a system in which columns of water circulating through pipes are substituted for the rods. This apparatus is composed, Fig. 4092, of two distinct parts; one placed near the motor at any distance from the well, the other fixed at the bottom of the well, at 4 or 5 mètres at the most from the level of the water; these two parts are connected by two conduit-pipes O P, R Q.

The apparatus being filled with water, which may be easily done at first starting, suppose the piston C of the upper pump moved forward. It will force the water down the pipe O P, closing the valve *o*. The pressure will be transmitted integrally to the piston K of the lower apparatus; the two pistons K and L, fixed upon the same rod, will move in the direction contrary to that of C, and will force the water up the pipe Q R, opening the valves *s* and *q* and closing *t* and *r*. As the compartments E and G have each a volume equal to that of the cylinder of the upper pump (an essential point), the quantity of water raised will be double that forced by the piston C. Only half

of the total volume of water raised will go to fill the empty space B, whilst the rest will pass through the valve p, and enter the pipe S T. When the piston C moves in the contrary direction, the same effects will be produced the other way, and a cylinderful will be raised at each single stroke.

4092.



This pump has been applied to several mines of great depth. We do not know of any experiments made to ascertain its percentage of work; but it is probably not lower than that of common pumps, the friction of the water in the pipes being substituted for that of the long rods. It has, however, one grave defect; on account of the sudden change of direction in the motion of the water at each stroke of the piston, ramming shocks are produced which, in a large pump, might cause breakages. To lessen the chances of accident, the two conduit-pipes must be fixed very rigidly, a condition difficult to fulfil in the case of great depths.

Laburthe's Compressed-air Pumps, Fig. 4093.—M. Laburthe's pump is an extremely simple one. The pump, which is placed at any distance from the water to be raised, consists of an air-piston moving in a cylinder, which, by means of an iron pipe, is placed in communication with a box sunk in the well, and provided

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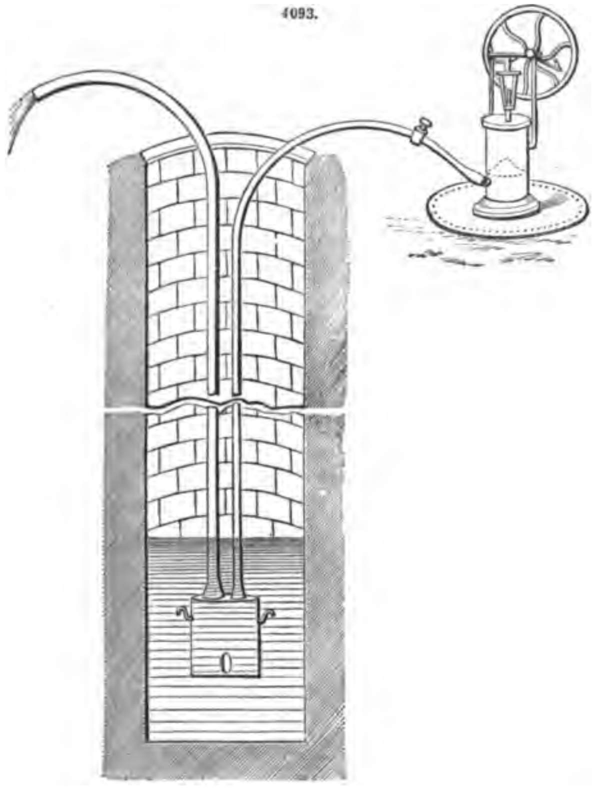
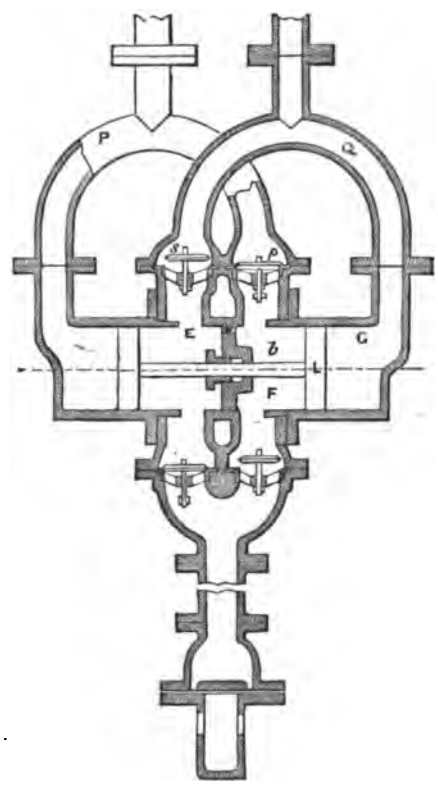




with a valve opening inwards. A second pipe goes from the bottom of the box to the point where it is required to discharge the water. By giving the piston an alternating motion, which is accomplished by the usual means, the compressed air in the abductor-pipe forces the water up the ascending pipe until the box is filled with air at the pressure of the ascending column. At this moment some more water must be let into the box, and to effect this a cock placed upon the upper part of the abductor-pipe is opened. Atmospheric pressure is thus restored in the box, the water of the well flows into it through the valve, and the same action is repeated. Care must be had to provide the bottom of the ascending pipe with a stop-valve. Besides this, the capacity of the box should be considerably greater than that of the ascending pipe, in order that it may not be necessary to interrupt frequently the action of the pump for the purpose of restoring atmospheric pressure in the box. This condition cannot be fulfilled practically

except in the case of pumps that are required to give only a small quantity of water such as those for household purposes. Obviously the action of the pump is independent of the depth, and it is sufficient to give it dimensions proportionate to the height to which the water is to be raised. This arrangement is simple, cheap, and convenient. It is to be feared, however, that the air-pump would require great care to keep the piston air-tight, a task of some difficulty in dealing with compressed air. The percentage of work must be very low, for, by opening the cock for the purpose of restoring the atmospheric pressure, an amount of work is instantaneously lost corresponding to that requisite to compress the air in the box to the pressure of the ascending column.

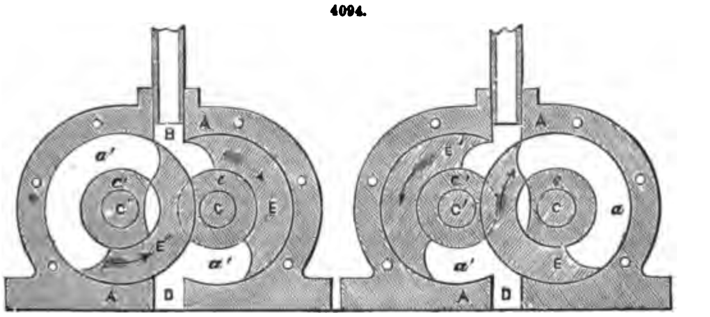
Some of the machines which we have already described might be ranged under the head of unlimited pumps; such, for example, as Durozoi's propeller and Bastier's chain-pump.

Rotary Pumps.—Revolving-piston Pumps.—As the change of direction in the motion of the water, which takes place in common pumps at each stroke of the piston, constitutes a defect that prevents the attainment of a high rate of speed, some engineers have been induced to substitute rotary pumps for them, in which this objectionable feature is absent. They consist, for the most part, of a cylindrical box in which revolve one or more pistons, which drive the water before them; they are provided with springs arranged so as to prevent communication between the inlet and the outlet pipes. Stolz's pump, for example, is constructed upon this principle. It may be used for domestic purposes, on the condition that only clear water is raised, and that the pump is well constructed. The percentage of work is usually low.

Leclerc's pump, instead of revolving pistons, has two toothed wheels which gear into each other inside a box, and drive the water before them always in the same direction. Another system is to roll an india-rubber tube around the water-box, or, as it is more usually termed, the pump-well. This tube, which is full of water, is compressed by a roller revolving about an axis. This system, however, can be applied only on a very small scale.

There are others belonging to the same order of ideas as the preceding, but they have all the grave defects of being complicated, expensive to repair, and of little useful effect. For these reasons rotary pumps have been abandoned everywhere, except perhaps in America, where they have been more successfully treated. One of the latest improvements effected in this direction by the inventive genius of the Americans, is *Behren's Rotary Engine*, Fig. 4094, made by Dart and Co., of New York, which possesses some original and novel features. The inventor claims

4094.



for it the merit of being at once a steam or water motor, and a pump; but it is as a hydraulic machine that it may be employed with the greatest advantage. A cast-iron box or well, A, having internally the form of two portions of parallel cylinders entering each other (as shown in the figures), is in communication at B and D with the inlet and outlet pipes. Two parallel shafts, C, C′, pass through the box, as well as two fixed cylindrical sockets, c, c'; these shafts bear on the outside a spur-wheel of the same diameter, so that they turn in contrary directions and with the same velocity. Upon the shafts are fixed two pistons, E, E′, having the form of portion of a ring concentric with the shaft and the face of the box A. The outer and convex face of these pistons rubs against the face of the cylinders A, and their lower and concave face slides upon the fixed shaft-sheaths c, c', which are grooved to prevent the water from passing directly from B to D without impeding the revolution of the pistons. If the machine is to raise water, one of the shafts C, C′, is set in motion, and, as one drives the other, the pistons E, E′, are moved in contrary directions. By referring to the figures which represent two different positions of the pistons, it will be seen that the water entering through B will pass alternately through the annular spaces a and a', and will be seized successively by each piston during half a revolution, whilst the other piston, as it continues to revolve, will act as a check. We have here supposed the water to enter through B, because the figure may represent the machine employed as a motor; but it is obvious that if the direction of the motion is changed, the water entering at O will ascend through the pipe B.

It is not our business to examine here the value of this machine as a motor, still less as a steam motor; but as a pump it is very serviceable. It is simple, it fills only a small space, it may work with a high velocity, and it gives, without an air-reservoir, a continuous jet. It must, however, be made and put together very carefully. It would be interesting to know its percentage of work, but we have been unable to obtain information on this point We know only that in America it is employed in breweries and sugar-works, where it may be used to raise thick and hot liquids, on the condition, no doubt, that there be no suction of the hot liquids.

Centrifugal Pumps.—The idea of employing centrifugal force to raise water is of considerable antiquity; but Appold was the first to construct machines conveniently founded upon this principle; and so scientifically were his machines devised that even in the present day the best are those which most nearly resemble his model.

Centrifugal pumps are really water fans, formed of straight or curved blades, turning rapidly about a vertical or horizontal axis, and enclosed in a box. The water, entering through the centre of the wheel, is driven by the blades towards the circumference, and thence forced into the ascending pipe. At the same time the outward flow of the water causes a diminution of pressure about the axis, and this brings up the water from the lower reservoir. The height to which the water will ascend increases with the velocity of rotation. A simple calculation will show the relation between these two quantities. Calling the velocity in mètres a second at the end of the blades V, the extreme radius of these blades R, the number of revolutions a minute N, the weight of the water passing a second P, and the height of elevation H, we find (either by the expression of the centrifugal force, or by that of the *vis viva* due to the velocity V), neglecting the friction, that the work developed is $\frac{P V^2}{2g}$. This work, multiplied by the coefficient of the percentage of work, must be equal to the work effected, say P H, $K \frac{P V^2}{2g} = P H$; whence $H = \frac{1}{2g} K V^2 = 0 \cdot 051\, K V^2$. If it be required to introduce the number of revolutions into the formula, $V = \frac{2 \pi R N}{60}$; whence $H = 0 \cdot 00056\, K R^2 N^2$. Experiments have given, in the best centrifugal pumps, $K = 0 \cdot 65$; whence we deduce

$$H = 0 \cdot 034\, V^2 = 0 \cdot 00056\, R^2 N^2.$$

Appold's formula is $V' = 550 + 550 \sqrt{H'}$, V′ being the velocity at the circumference in English feet a minute, and H′ the height also in English feet, which gives, as the velocity in mètres a second, H being also expressed in mètres, $V = 0^{m} \cdot 84 + 4 \cdot 98 \sqrt{H}$; the formula which we have established above leads to $V = 5 \cdot 42 \sqrt{H}$. These two values of V agree sensibly for the ordinary values of H.

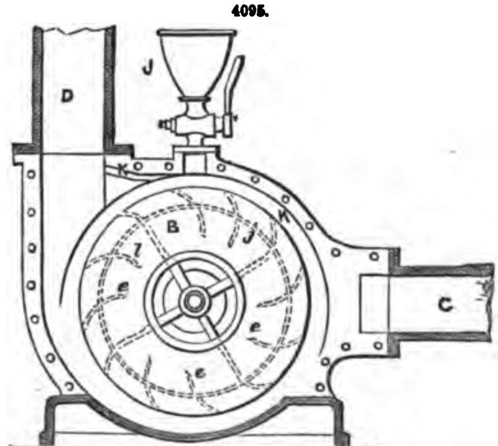
It is obvious that the velocity of these machines is necessarily great; they are therefore especially suitable for raising large volumes of water to a small height. An increase of velocity may either raise the water to a greater height, or increase the discharge.

The height of suction should be small, because the ascent of the water being due to the excess of atmospheric pressure above the pressure at the centre of the wheel, this excess must impart to the water a velocity sufficiently great to satisfy the discharge. If this condition is not fulfilled, the water does not enter in sufficient quantity, the machine gets out of water, and of course ceases to work. When circumstances will allow of it, it is well to avoid suction altogether, by placing the pump beneath the level of the lower reservoir; in which case the velocity of rotation may be increased without emptying the pump.

To utilize satisfactorily the motive work, the water must have a low velocity in the inlet and delivery pipes, and a high velocity in the wheel only. The form of the blades should be such that the fillets of water may enter them almost without shock, and especially nearly tangentially to the outer circumference. This condition can be realized only by means of curved blades; a fact that was proved by experiments made in the London Exhibition of 1851, when wheels with curved blades, with straight blades inclined upon the radius, and with straight blades radiating from the centre, were successively placed in the same machine. The percentage in each of these cases for a height of from 15 to 18 ft. was 0·67, 0·42, and 0·24.

It is also necessary that the water, in passing from the very low velocity which it has at the centre of the wheel, to the high velocity of the circumference, should traverse gradually-diminishing sections. In the same way the sections of passage must increase from the point where the water issues from the blades to the ascent-pipe. By thus making the sections inversely proportional to the velocities, the eddying and whirling, which absorb a portion of the work, are avoided. The first result may be obtained either by varying the thickness of the blades so as to give their concave side a different form from that of their convex side, or, as in the case of Lloyd's fan, by making the blades of a uniform thickness, and by diminishing their breadth from the centre of the wheel. The blades are in this case enclosed between two lens-shaped covers widening towards the centre.

4095.



We will examine here some of the best models.

Neut and Dumont's Centrifugal Pumps.—These closely resemble Appold's type; the water brought in by the conduit-pipe C, Figs. 4095, 4096, at the height of the axis, separates into two currents *d* that lead it to

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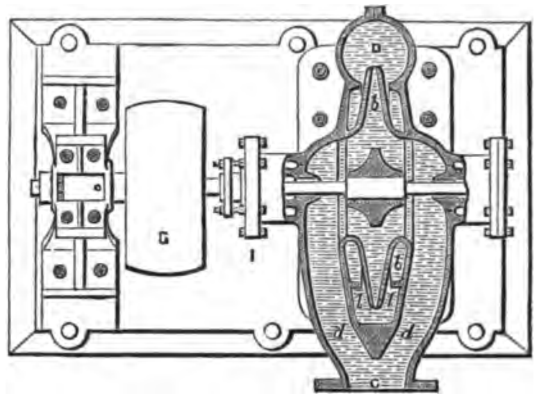
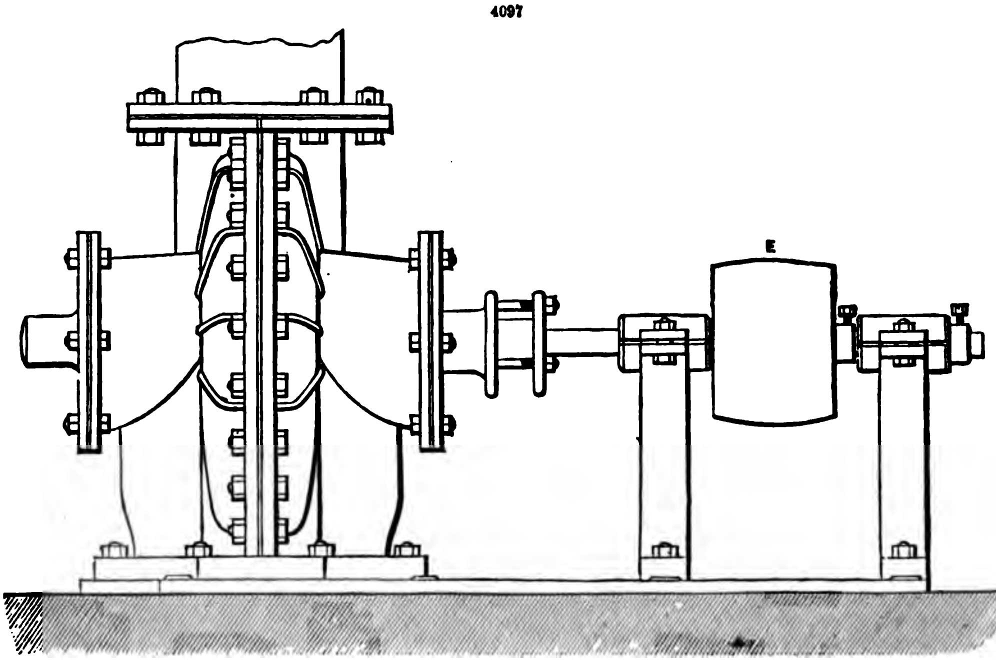


the centre of the wheel, which is formed of two cheeks *b*, between which are the blades *c e*; some of these reach to the nave and are fixed to it, their breadth diminishing from the centre to the circumference. Some circular partitions force the water issuing from the wheel to follow an annular conduit K, the section of which increases progressively up to the ascent-pipe D; this *partly* realizes the conditions indicated above. The body is formed of two symmetrical pieces bolted together; it is traversed by the horizontal shaft X which passes through stuffing boxes and carries the transmission pulley G. The whole rests upon a single bed-plate I. The funnel J serves to fetch the pump at starting. The orifice K′ gives an outlet to the air which may lodge itself in the upper portion. To prevent the air from getting through the stuffing box, the latter is put in communication with the delivery column by means of a pipe constantly filled with water; and, in case the air should get into the centre through the suction-pipe, in order to fetch the pump again without stopping it, two holes are provided which put the centre of the wheel in communication with the interior of the chamber into which the water is forced; this forces the air to escape.

During some experiments made to ascertain the percentage of work, one of these pumps, having a diameter of wheel of $0^{m}\cdot300$, with suction and forcing orifices $0^{m}\cdot250$ in diameter, raised 138 litres a second to a total height of $5^{m}\cdot50$; the velocity being 500 revolutions a minute, the mean percentage of work was 57.

Centrifugal Pumps of Messrs. Gwynne and Co., of London.—These complete and powerful pumps were originally constructed with straight blades, radiating from the centre and provided with a circulation-pipe; but the percentage of work was very low, only 19. Later, profiting by the lessons taught by the Exhibition of 1851, they modified them in the direction of Appold's plan, by curving the end of the blades so as to bring them almost tangentially to the circumference of the disc. This is shown in Figs. 4097 to 4100, which represent a pump of $0^{m}\cdot460$ in diameter. The water entering through H, separates into two currents H′ and H″, which enter through the centre of the wheel K′, K″, to issue through the circumference and flow thence to the pipe Z. The blades, six in number, only three of which reach the nave, are of cast iron 14 millimètres thick, curved and bevelled on the outer circumference so as to be only 1 millimètre thick at the

4097



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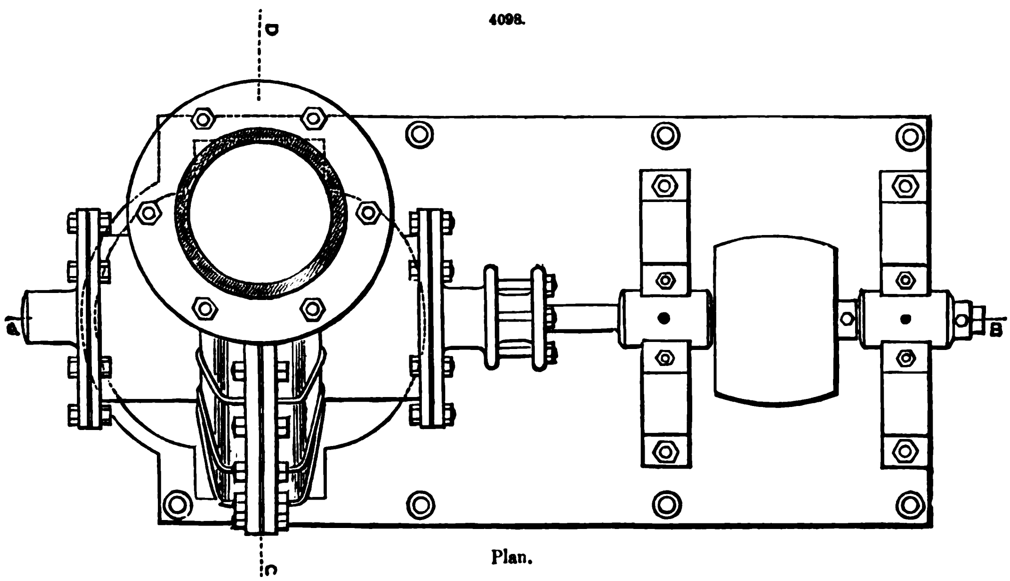
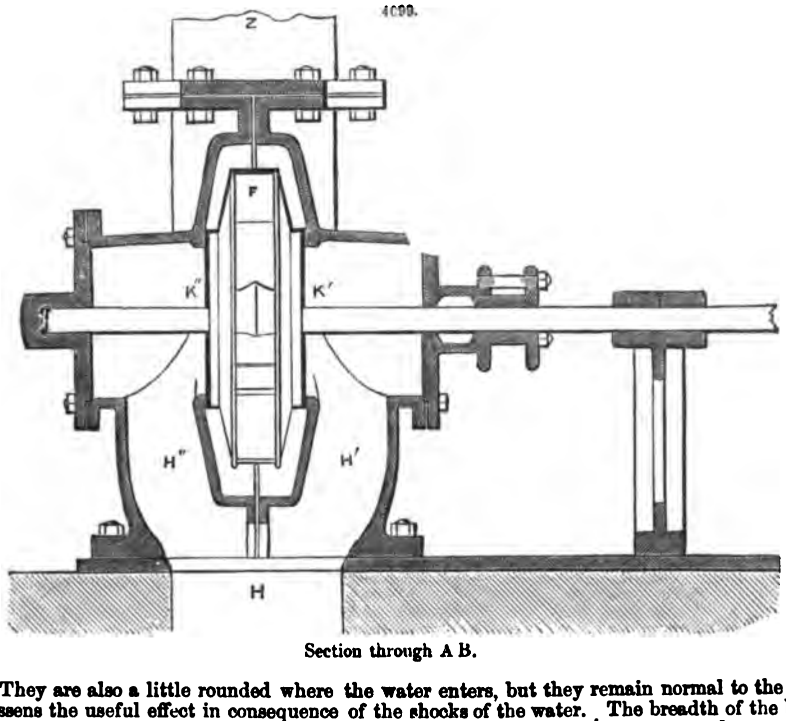


Plan.

4099.

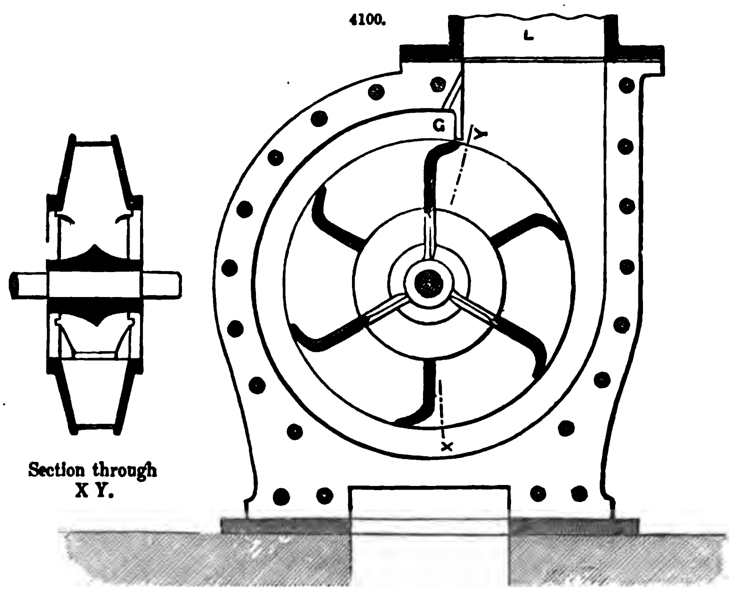


Section through A B.

end. They are also a little rounded where the water enters, but they remain normal to the nave; this lessens the useful effect in consequence of the shocks of the water. The breadth of the blades and their envelope, at first uniform, decreases afterwards up to the end, so as to produce a section varying in an inverse direction to the velocity of the water at different distances from the centre. On issuing from the wheel, the water first passes through an annular space which takes it to the delivery-pipe. A diaphragm G prevents a partial return of the water into this annular space, and an orifice furnishes an outlet to the air which tends to collect at G.

This pump was subjected to experiments at the Conservatoire des Arts et Métiers at Paris, for the purpose of ascertaining its percentage of work. The diameter was $0^{m} \cdot 460$. The height of aspiration was $0^{m} \cdot 80$, and the forcing height $9^{m} \cdot 50$. The number of revolutions varied from 630 to 700 a minute. The maximum useful effect was 0·52, corresponding to 670 revolutions, and to 7 litres of water raised by each revolution. The minimum was 0·32, corresponding to 640 revolutions and 4·75 litres a revolution. The gross mean may be fixed at 0·45.

4100.

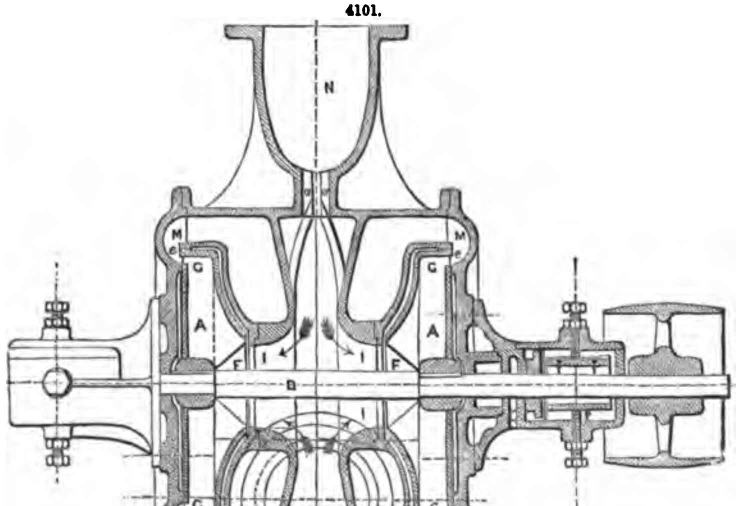


Section through X Y.

Section through C D.

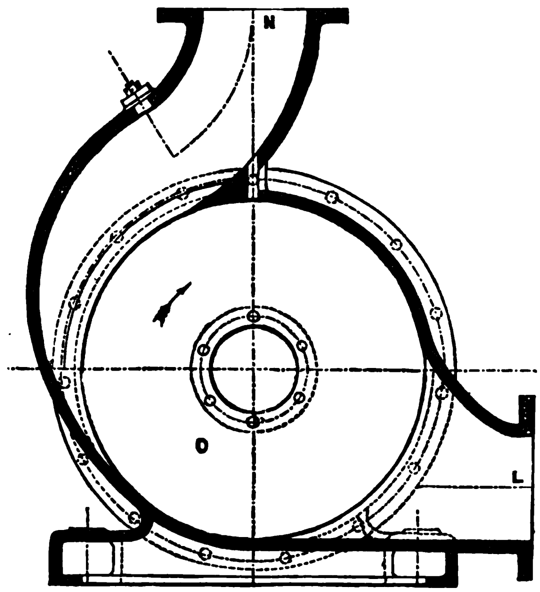
Coignard and Co.'s Centrifugal Pumps, Figs. 4101, 4102.—In these pumps Coignard and Co., of Paris, have substituted for the blades in Appold's machine, two revolving pieces A, which they call screws, placed symmetrically upon the spindle D. The water, brought through the pipe L O to the centre of the wheel I, passes through the orifices F into the screws, which impart to it an increasing velocity up to the circumference at G; thence it flows through the conduits M into the common ascending pipe N. The small orifices *e* afford an escape for the air which may collect at the top of the pump. The form of the screws is such that the section of passage decreases from the centre to the circumference, and increases from the issues M up to the delivery-pipe, so as to vary inversely with the velocity. This condition is favourable to the work of the pump, as we have seen above, but the sharp angles, as G, *e*, M, must cause a slight resistance. The construction of these pumps is certainly good; the axis passes through two stuffing-box glands P, the pressure of which may be regulated at pleasure. The whole rests upon one bed-plate.

4101.



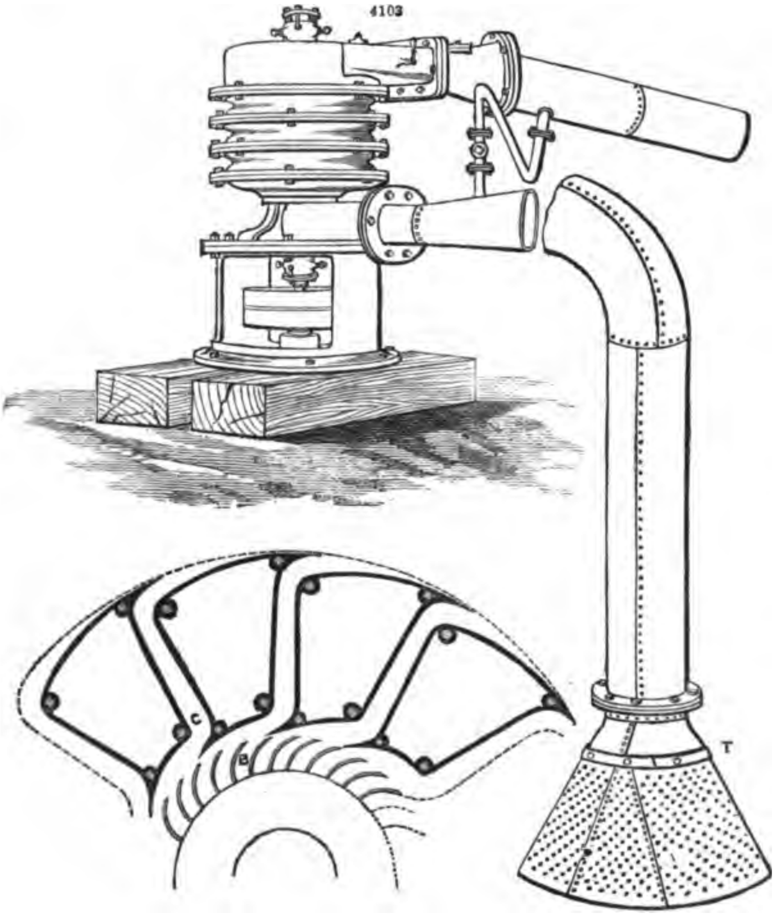
Centrifugal pumps are very serviceable when the height of ascension is not great. They possess the advantage of being adaptable to a varying discharge, and even a varying height, a change of velocity being all that is necessary to render them adequate to the case in question. They are easily

4102.



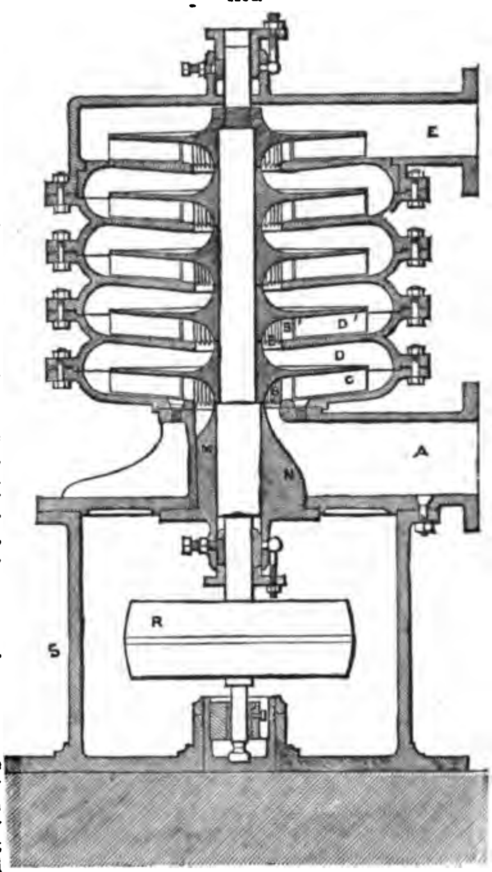
erected and removed, and the absence of valves, except the foot-valve when there is suction, renders them capable of raising dirty water. They always require an inanimate motor. Their chief defect is their great velocity, which cannot be increased above a certain limit without injury to the stuffing of the axis. Attempts have been made to overcome this difficulty, in cases of a great height, by placing several centrifugal wheels upon the same spindle, the water forced up by the first entering into the axis of the second, which takes it up to the third, and so on. The consequence of this is, that the increase of pressure produced in each wheel is added to the others, and that the final pressure for a given velocity increases with the number of discs. This ingenious idea was first applied by John Gwynne; he succeeded in this way in increasing the height of elevation without increasing the velocity of rotation, but at the cost of useful effect. There was a loss of work in passing from one wheel to the other, on account of the sudden changes in the sections of passage, and in the direction of the plan of the water. M. Girard has improved the construction of this machine, and named it the "Lifting turbine," drawings of which are given in Figs. 4103, 4104. It consists of a number of similar wheels, placed one above another and

4103



fixed upon a vertical spindle, the whole being enclosed in a cast-iron casing forming partitions between the wheels. The water entering through A is sucked up to the centre, B, of the first wheel, and driven along C D up to the centre, E, of the second, which in its turn drives it along B′ D′, and so on up to the delivery-pipe E. The curves of the blades and of the envelope, or casing, are carefully studied, with a view of making the sections of passage vary progressively, according to the velocity which the water is to have in them, and so to lessen the effect of the sudden changes of direction and of velocity. Each wheel contains 36 curved directrices, B, corresponding to which are 12 channels, C. As details of construction, we may remark that the arrangement of the pivot and collars of the spindle is such that they may be regulated at pleasure; that the tube placing the delivery-pipe in communication with the suction-pipe is intended to prevent the pump from getting out of water in consequence of the entrance of air, and that the rose T at the end of the suction-pipe is for the purpose of keeping out solid matters, which might cause a breakage.

4104.



Section through the axis.

Experiments were made with this machine at the Conservatoire des Arts et Métiers, at Paris, the height of suction being, in this case, $1^{m} \cdot 74$, and the height of delivery varying from 4 to 10 mètres. The following are the means of the results obtained from a model constructed with the latest improvements in details:—

Number of revolutions a minute	300	400	400
	mètres.	mètres.	mètres.
Height of delivery ..	4	4·20	7
Volume of water raised a minute	2800 to 4000 litres.		
Percentage of work ..	0 35 to 0 40.		

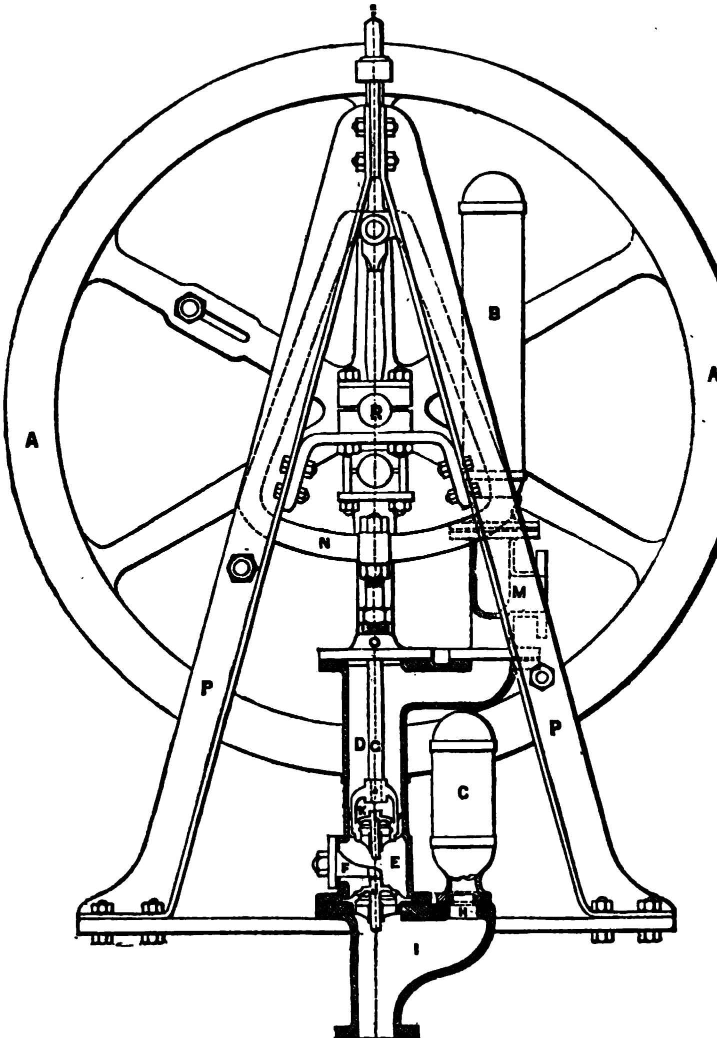
These figures show that, for a determinate height of delivery, the velocity is considerably less than that of a centrifugal pump with one disc; but this advantage is obtained by a loss in the percentage of work, and it must be added that the machine is heavier, and consequently more costly and less convenient.

The India pumps, designed and manufactured by Merryweather and Sons, London. These pumps are termed *India pumps* because they are much employed in *India*.

Fig. 4105 is a side elevation of this pump, with the pump-barrel, valves, and suction-breech in sections, Figs. 4106, 4107. A is a stout cast-iron fly-wheel, which is the only piece of cast iron about the whole machine; B is the copper delivery air-vessel, which steadies the stream of water when pumping through a hose, if used as a fire-engine, or when used as a pumping engine prevents concussion in the discharging main; C is a copper suction air-vessel placed in the suction-breech of pump; D, pump-barrel, of which there are two; E is the valve-chamber at lower end of pump; F is the door of the valve-chamber, with a stop-piece to regulate the lift of valve in suction; G is a copper pump-rod, connected at lower end to the spindle-bucket, and at upper end to the kite; H is the passage from breech-chamber to suction air-vessel; I is the suction-breech of pump; J is the suction spindle-valve complete, with its valve-seating arranged so that the whole can be taken out of the pump in one piece if required; K is the bucket fitted with spindle-valve and leather cup, L; R is the crank of motion, working on gun-metal bearings, and mounted on wrought-iron cross-bearers bolted to framing; M, the delivery-piece of pump, to which either flanged pipes may be attached for filling tanks or a screw connecting-piece to receive hose; N, the wrought-iron kite motion to which connect the guide-rods at top and the pump-rod at bottom; O is the gun-metal cover of pump, fitted with stuffing gland and nut; P P, the wrought angle-iron frames carrying the whole of the machinery.

Fire-engines.—Though fire-engines are a kind of forcing pump, yet they differ from this latter in the conditions which they have to fulfil. In the common forcing pump, we give to the water the least velocity possible, in order to utilize to the fullest extent the motive power employed: but in the case of a fire-engine, on the contrary, velocity is the chief object in view. The water has to be thrown to a great height, and in such a way that the jet may overcome the resistance of the air without being divided into spray too soon. The velocity of issue, for given dimensions and number of strokes, depends on the diameter of the orifice of the spout-pipe, and this diameter must be made proportionate to the volume of water to be thrown, and to the distance or length of jet. In 1862 experiments were made in London for the purpose of ascertaining the influence of the size of the jet

4105.



upon its efficiency. These experiments, made with some English pumps and a Letestu pump, led to the conclusion that a large diameter at the end of the spout-pipe is favourable to the effect which it is required to produce, namely, to throw the water to a great horizontal and vertical distance without losing any of it. Thus the English pumps, with an orifice of 20 or 22 millimètres in diameter, were effective at a distance one and a half times greater than that of the French pump with an orifice of 14 millimètres, and the ratio of the quantity of water utilized to the quantity thrown from the spout-pipe was greatly superior for the former. We have no figures relative to the *work* of a fire-engine; but the matter is not one of great importance. Probably 30 per cent. would not be far wrong for the best-made engines.

Steam fire-engines were first used in America. A capital point in this kind of engine is the necessity of having a boiler capable of producing a sufficient quantity of steam in the least possible time, and to this point makers have chiefly directed their attention.

Lee and Larned's Steam Fire-engine.—Lee and Larned, of New York, were the first to construct an engine of this kind. It is provided with a vertical boiler similar to Field's system, that is, furnished with vertical water-tubes closed at the bottom and in communication at the top with the principal body. These tubes are placed in the fire-box, which is itself surrounded by sheets of water; concentric with the first are other tubes, open at both ends, which keep up, in consequence of the decreased density of the heated water charged with steam, a very active circulation, and consequently a rapid vaporization. The pump is rotary, and is driven by a steam-piston having a reciprocating motion and a short stroke. Two fly-wheels served to carry the pump over the dead-points: the whole machine fills only a small space, and it works at a high rate of speed. The engine, with its frame, is carried upon four wheels; the boiler rests directly upon the

back axle through the medium of a spring; the remainder of the engine rests upon the fore axle by means of two springs.

Mazeline's Steam Fire-engine.—To the Messrs. Mazeline, of Havre, is due a modification of Lee and Larned's system. In the place of rotary pump, they have substituted two horizontal water-cylinders, with plungers driven directly by two pistons. The common stroke is $0^{m}\cdot220$, the diameter of the plungers $0^{m}\cdot152$, and that of the pistons $0^{m}\cdot236$. The valves are worked directly by rods, without the medium of eccentrics. There is no fly-wheel, nor any revolving parts. The boiler is vertical, and has a heating surface of 22 square mètres.

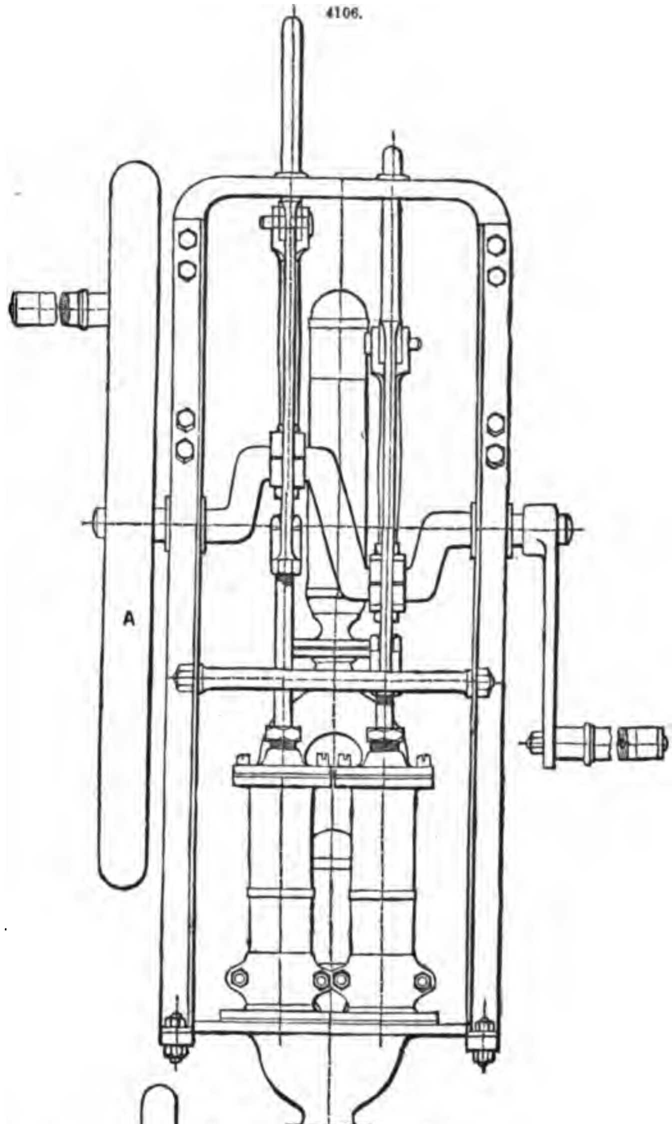
Steam Fire-engines of Merryweather and Sons, London, Figs. 4108 to 4112.—Merryweather's lesser engines comprise a horizontal double-action pump worked directly by the steam piston-rod T, Fig. 4110. The slide-valve is worked by the piston-rod, and there is no fly-wheel. The boiler, which is placed behind, is one of Field's system, Fig. 957, like those of the American engines. The whole rests upon a strong iron frame supported upon wheels by means of springs. Seats for the firemen are placed in front, and a reservoir of air completes the engine. See ENGINES, VARIETIES OF, p. 1429, Figs. 2729 to 2732.

The large engines of Merryweather are the same in design, but double. They contain two horizontal direct-action water-cylinders B B, Fig. 4109, and the same number of steam-cylinders. The distribution of the steam is effected as in the small engines, by means of the rods; there is no fly-wheel. The boiler, as in the former case, is one of Field's, and may be fed either by a Giffard injector or by a small pump, which is preferable.

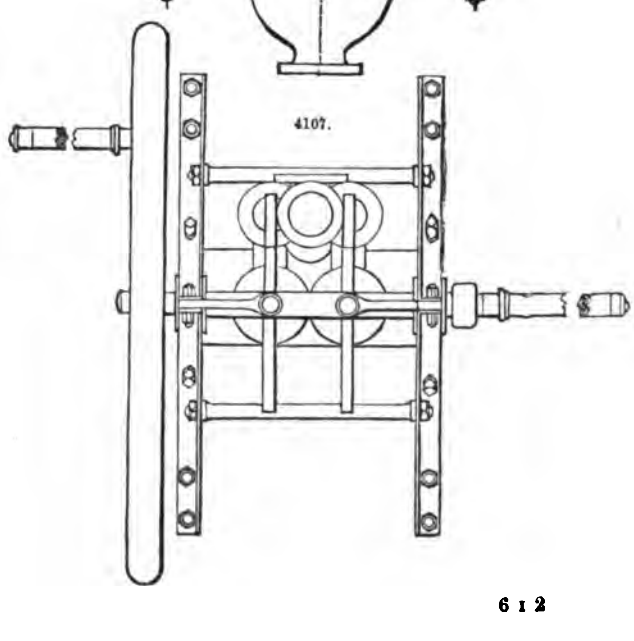
The points to be remarked in these engines are the good construction of the boiler, which is capable of getting up steam in a few minutes while on the way to the fire, the suspension combined so as to cause but little oscillation, the long stroke of the pistons and the large volume of water thrown at a stroke, which allow of a reduction in the velocity.

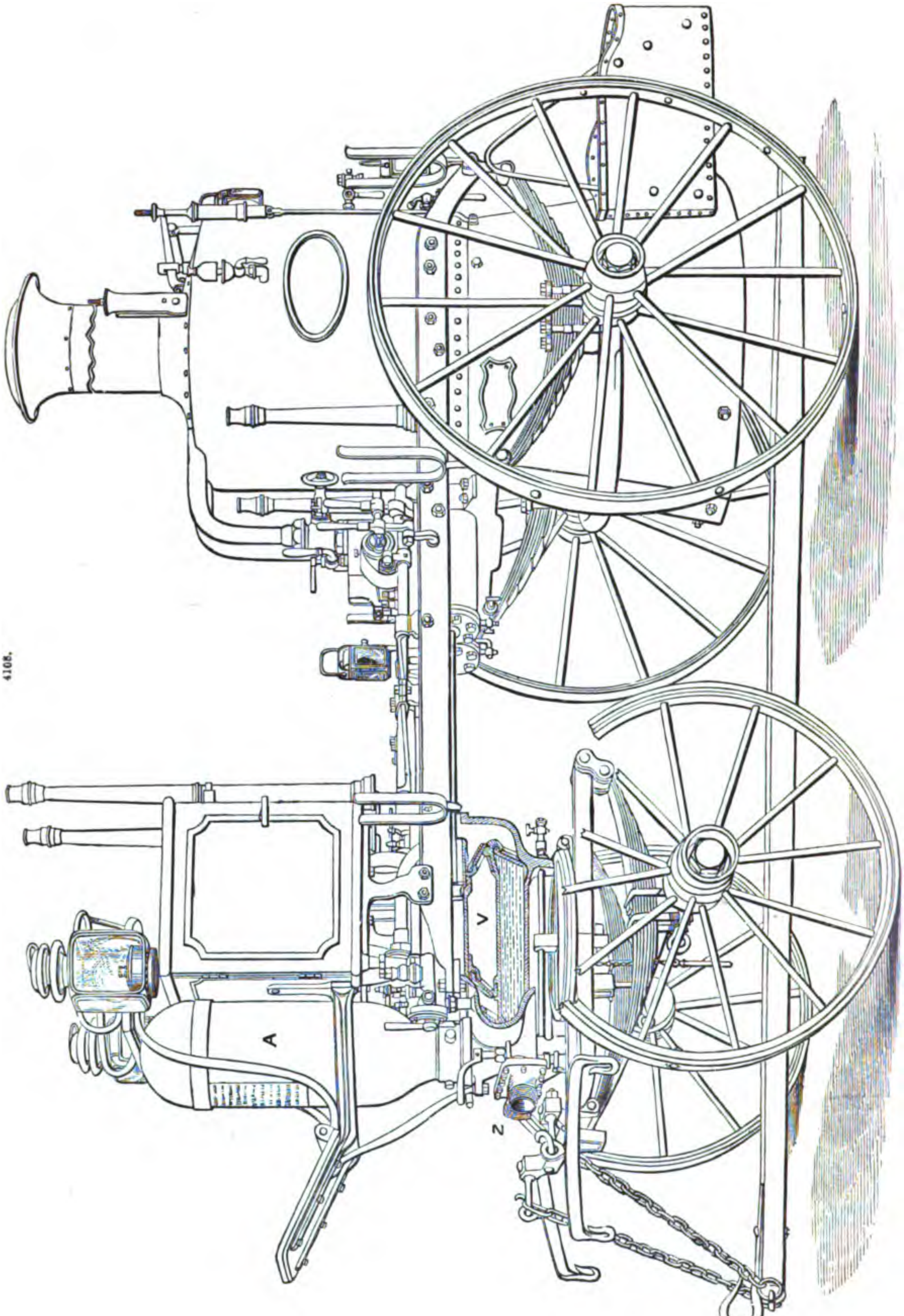
At the Paris Exhibition

4106.



4107.



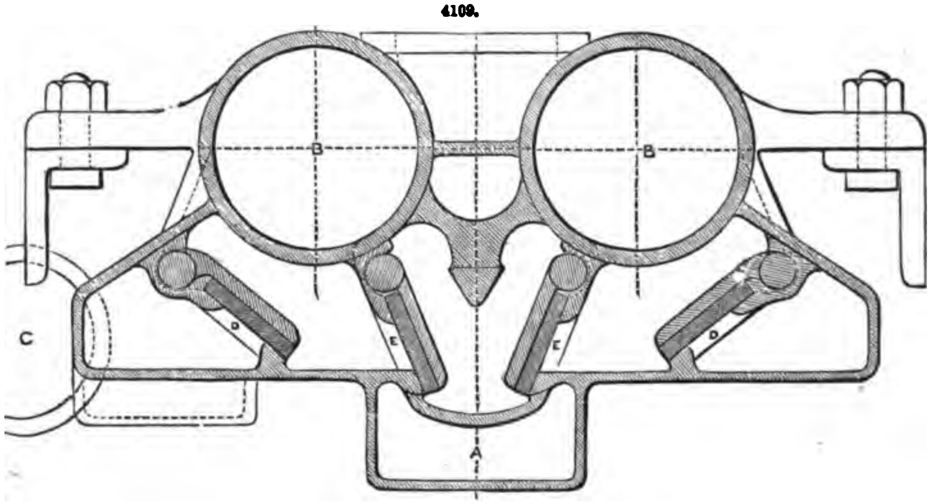


4108.

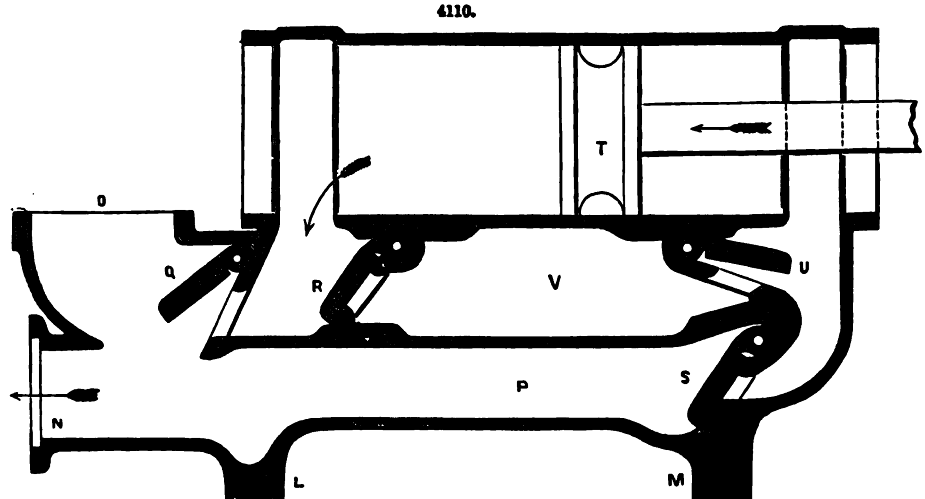
of 1867, experiments were made with the engines described above, and one of Shand and Mason's engines. The water was taken from the Seine through a suction-pipe $2^m \cdot 50$ long, the delivery being 100 mètres. The lighthouse served as an object to measure the height of the jets by. The boilers having been filled with cold water, the fires were lighted. In 10½ minutes, Merryweather's boiler reached a pressure of seven atmospheres. The engine was then started, and the pressure having increased, maintained itself for an hour between eight and nine atmospheres. Shand and Mason's engine was 13 minutes in getting up steam, and the jet was irregular, especially at starting. One of Mazeline's large engines was then tried against a Shand and Mason; the former was unable to keep up the pressure, and the latter worked badly. On the following day, Merryweather's large engine worked alone throughout the whole day, and in a very satisfactory manner. It threw the water with great regularity either in one jet of 45 millimètres or in four jets of 25 millimètres. We have carefully examined most of the hydraulic machines, termed steam fire-engines, employed in Europe and America to extinguish fires; each of those machines possesses one, two, or more peculiar points of excellence, but the engines that satisfy the required conditions most effectually are those of Merryweather and Sons, of London. These engines can remain longer neglected and out of use, without impairing their action, than any other fire-engine which we have examined; this essential property is often overlooked when the relative merits of these hydraulic machines are being compared.

Figs. 4109, 4110, are sections of one of Merryweather's improved double-cylinder steam fire-engine pumps, with doors placed at ends, so that the valves and their seatings can be drawn out in

4109.



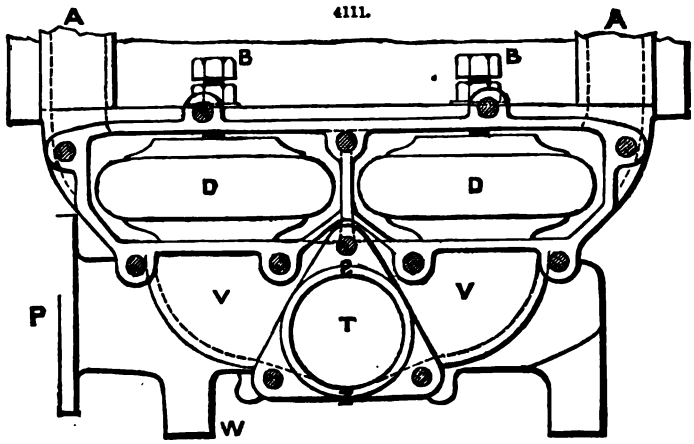
4110.



a few minutes in their entirety. The valves and water-passages are below the pump-barrels, and as the pump is entirely empty when the pump is at rest, there is no fear of its being affected by the frost. Another point of advantage in this class of pump is that the barrels will work both foul

and gritty water without injury; throughout the passages are very capacious, and being unobstructed by gratings will pass muddy water, sea-weed, or any other foreign matter that is in the water. The pistons of this class of pump are self-lubricative, and seldom want attention; this is a feature that has never before been obtained in double-acting pumps.

4111.



A, Fig. 4109, is the delivery of pump; B B, pump-barrels; C, the suction-inlet of pump; D D, the suction-valves; E E, the delivery-valves. The body of the pump is of one entire casting, and of gun-metal.

In Fig. 4108, V shows the position of the valve, of which Figs. 4109, 4110, are sections; A, Fig. 4108, is the air-vessel. The piston T, Fig. 4110, moving in the direction of the arrow, half its stroke being made; the valves U, Q, are open, and R and S closed. The valves Q, U, are closed and R, S, opened when the piston T makes its return stroke, but the delivery, through P N, is continuous and in the direction of the arrow N. O, Fig. 4110, is the passage-pipe to the air-vessel A, Fig. 4108. The valve-cover and the supports L, M, are cast in one piece. In our article, ENGINES, VARIETIES OF, p. 1430, we referred to Merryweather's valves, Figs. 4111, 4112.

4112.

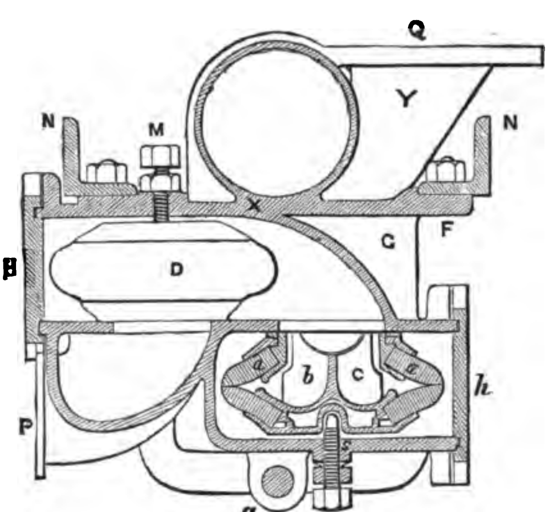


Fig. 4111. A A are the openings from the valves to pump-barrel; B B are the screws for holding the valves, and adjusting the same; D D are the disc lip suction-valves of Field; P is the discharge or outlet passage from pump; S the face of cover for side suction; T, suction-passage; V V, suction-passage leading direct to valves; W, bracket for fixing pump; Z, suction-flange.

Fig. 4112. *a*, *a*, the india-rubber disc lip-valve of Field; *b*, *c*, gun-metal guide for valve; D, suction-valves; F, flange or leg for fixing pump to frame; G, water-passage; *g*, bracket for fixing pump to frame; H, *h*, suction and delivery covers; M, the screw for holding valve, and adjusting the same; N, angle-iron frames, to which pump is bolted; P, suction-passage; Q, delivery air-vessel flange; S is same as M; X, body of the casting of pump; Y, delivery-passage.

Centrifugal Pumps, Figs. 4113 to 4121, *of John and H. A. Gwynne, of Hammersmith.*—These centrifugal pumps are very durable and mechanically complete; they are hard to be disarranged, but easily repaired.

We take the following description from the specification, 30 July, 1868, of John Gwynne and Henry Anderson Gwynne, of Hammersmith;—

The improvements in the construction of centrifugal pumps, Figs. 4113 to 4121, consist in the making of the impeller without the usual discs or side plates. This impeller J. and H. A. Gwynne prefer to make of cast steel, thus forming a much lighter and equally strong motor. This form of impeller is especially adapted to the form and construction of centrifugal pumps ordinarily made by this firm.

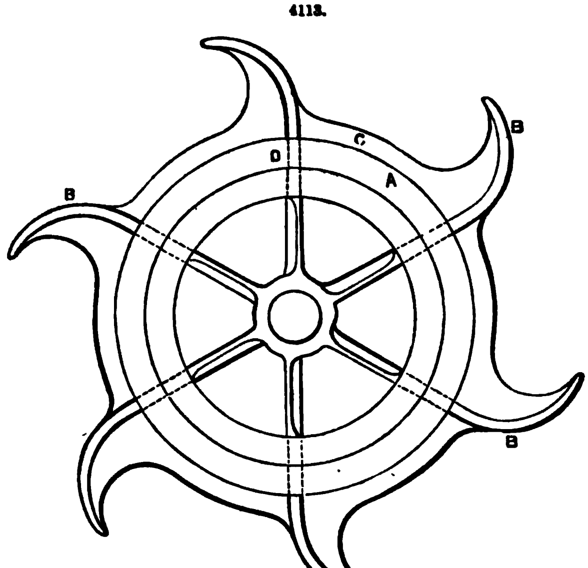
In order to vary the speed between that of the engine-shaft and the centrifugal pump, the inventors propose to employ a novel arrangement and construction of frictional wheels with one square or angular-shaped groove in the one and corresponding projection upon the other fitting into the aforesaid groove, the amount of friction between the wheels being regulated in the following manner;—The wheel with the square or angle-shaped groove is divided into discs, and when in working order these discs are separated from one another a short distance, and held in that position by bolts and nuts, or a traversing central nut. When from any cause it is required to vary the amount of friction between the wheels, the bolts holding these discs are tightened or slackened

accordingly; or, in other words, the lateral distance between these discs is varied. If preferred, the wheel having the projection may be similarly varied, or each wheel may have grooves and projections upon their faces alternately. There may be several such discs or grooved and beaded wheels mounted on the same shaft or shaft at any convenient distance apart. These wheels may be used for driving other descriptions of machinery, and employed for the purpose of transmitting motion.

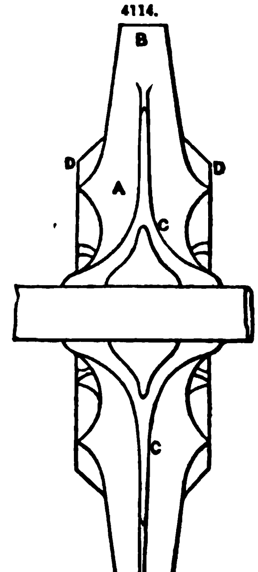
For the purpose of condensing the exhaust steam of the engine working the pump, the inventors make the suction or delivery pipe of the pump, for a certain portion of its length, of thin metal, and enclose this length within a casing of greater diameter than the pipe, so that an annular space or chamber is formed by closing it at each end. This annular space or chamber forms a condenser for the exhaust steam from the cylinder of the engine, which, upon being caused to pass into it, is immediately condensed by contact with the cold metallic surface;—maintained cold by the circulation of the water passing through the internal pipe. An air-pump is fitted to this annular condenser in the usual manner, or this water may be removed from the condenser by having a vertical pipe leading downwards of sufficient length, a steam trap being placed at the bottom of it, or by a pipe leading into the suction-pipe of pump, a vacuum being formed by the velocity of the water. If preferred, the condensing chamber may be enlarged and the inside pipe perforated so as to condense the steam more rapidly, a combination of the water-jet and surface condensation being effected within the same vessel; or the exhaust steam may be blown directly into the discharge or suction pipe of the pump. The pipe of the centrifugal pump, where used as a condenser, may be corrugated or fluted to expose a larger surface or area, or the suction-pipe may be enlarged and two or more pipes introduced therein. This condenser or a second condenser upon another portion of the suction or delivery pipe of the centrifugal pump may be used for the purpose of condensing the steam of any other engine conveniently near, instead of, or in addition to, the driving engine employed for working the pump. This form and arrangement of surface condenser is also applicable to the pipes of any other pumps and to other hydraulic machinery, through which or by means of which a considerable current of water is produced or set in motion.

Fig. 4113 is a side elevation, and Fig. 4114 a front sectional elevation, of the disc or impeller A, which in this case has six arms B, but any other number of arms may be employed; these arms

4113.



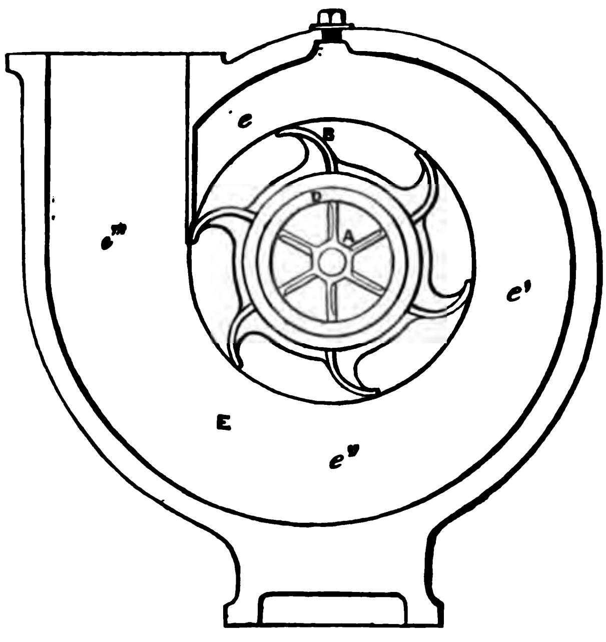
4114.



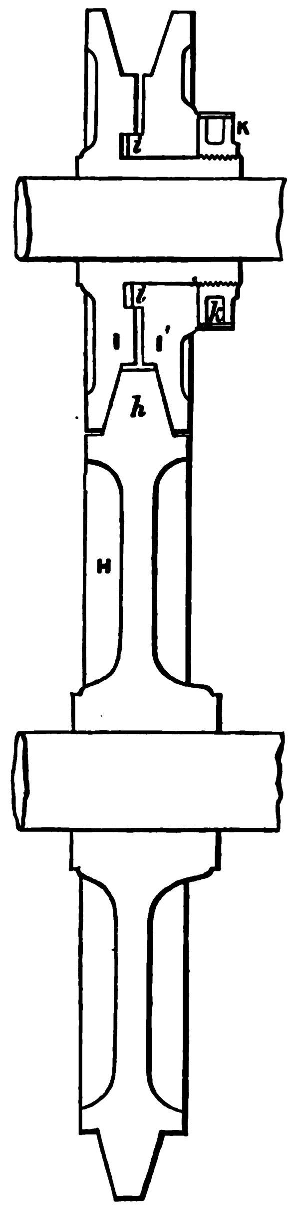
are cast in one piece with the boss. A centre plate C springs from the boss, gradually decreasing in thickness until at the termination of the radial portion of the arms, the plate finishes with a knife-edge, or as thin as practicable, the object of this plate C being to separate the currents of water upon each side of the disc without producing an eddy or reflux. The arms are radial for about two-thirds of their length, curving off towards the periphery in an opposite direction to the line of rotation. Two rings D, one at each side of the arms, form the bearing surface, and we prefer to make the entire impeller or disc of one casting. Figs. 4115, 4116, are side and front sectional elevations respectively of the pump casing E, with the impeller or disc A fitted in position; F F are the suction-passages which branch off from the suction-pipe G at the point g. To prevent any obstruction to the water this bottom part of the casing E is thinned off to a knife-edge, as shown at g, and a space is left between the passage and the case to carry the suction-pipes F F over the enlargement of the discharge-passage in a straight line to the openings in the centre of the disc A, at which point they curve into the top of these openings. The discharge-passage is sprung from the periphery of the disc in the form of a helix or volute, commencing at the top of the case e, and gradually increasing at e^{1}, e^{11}, until at e^{111} it reaches the full size of the discharge-pipe. That

part of the pump casing E which contains the impeller A is made of the same shape as the profile of the impeller, and similar in section, and of just sufficient size to permit the impeller to revolve,

4115.

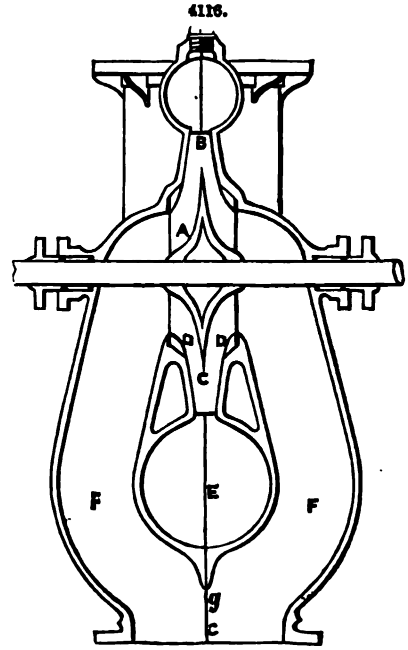


4117.



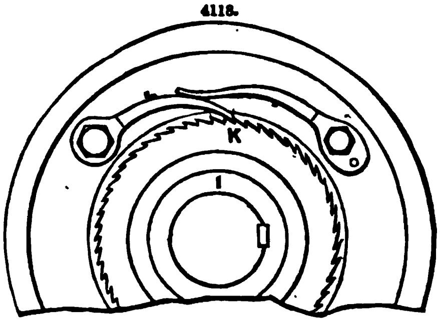
as shown in Fig. 4116, the bearing rings D being accurately fitted to the turned recesses in the casing. By this means the usual side plates on the discs of centrifugal pumps are not required, the peculiar form of the pump casing, as hereinbefore described, acting in the place of such plates, consequently the friction of the disc A is very much reduced, as the disc is accurately fitted on its spindle, and the bearing surface for the rings D, as well as the sides of the case, are carefully turned so that the arms fit, but without actual contact.

4118.



Figs. 4117, 4118, illustrate the second part of this invention, namely, an improved description of frictional gearing for driving centrifugal pumps or other machinery. Fig. 4117 is a cross-section of two wheels, or wheel and pinion, fitted according to this invention. In this case the larger wheel H has a projection *h* formed upon the periphery fitting into a recess of similar shape in the smaller wheel, or pinion, I I^1. This pinion is made in two parts or halves; one half, I, is cast solid with the boss of the pinion, this boss being turned on its outer side to receive the other half of the pinion I^1, which is accurately bored to fit the boss; the shoulder *i* is also turned to fit the recess formed upon the other half, I, of the pinion to give greater steadiness. This pinion is carried on

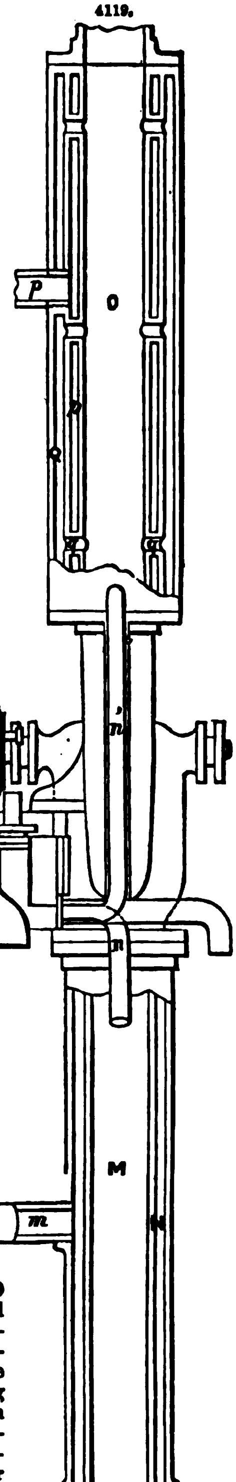
4118.

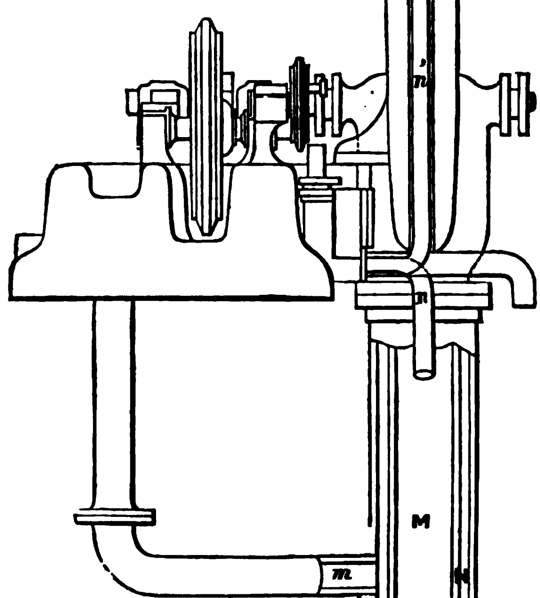


the shaft by means of one or more feathers, so that it is free to slide lengthwise upon the shaft. In order to adjust the friction between the wheel H and pinion I I^1 to any desired extent, a screw is cut upon the boss of the pinion, upon which a nut K is fitted, the inside of which bears against the half I^1 of the pinion, and consequently increases the pressure of the angular sides of the groove against the similar sides of the projection *h* upon the wheel H to any desired extent. The nut K is formed with a ratchet upon the outer edge, as shown in Fig. 4118, into which a pawl L works, and prevents the nut from slackening. This ratchet may be divided into any number of teeth, so that the nut may be held in any desired portion of a revolution, thereby obtaining great fineness of adjustment. The nut K is provided with holes *k* for the purpose of tightening or slackening it as may be necessary.

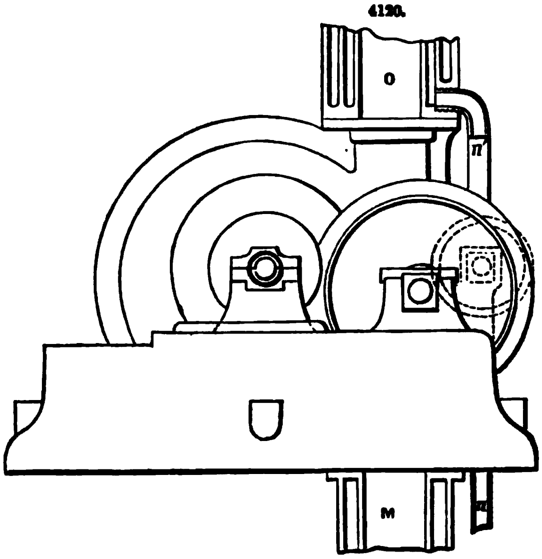
The third part of this invention is illustrated by Figs. 4119 to 4121, and consists of a novel arrangement of condensing apparatus for the purpose of condensing steam and adding to the power of the engine by bringing to the aid of the moving piston the vacuum produced by the condensation aforesaid; this is effected by utilizing the cold water passing through the suction or delivery pipe of a cold-water pump. In Figs. 4119, 4120, two

4119.

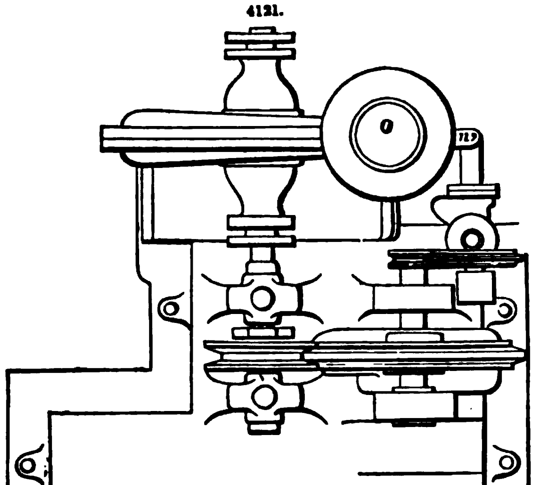




4120.

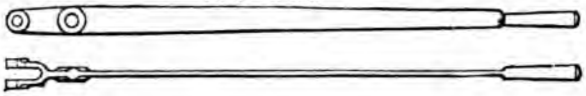


4121.



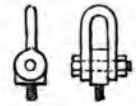
4129.

VALVE LEVER

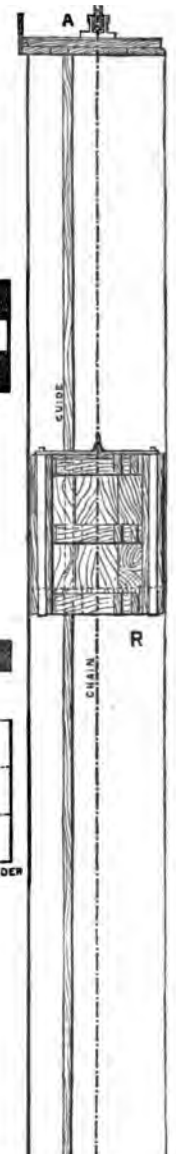


4130.

SHACKLE

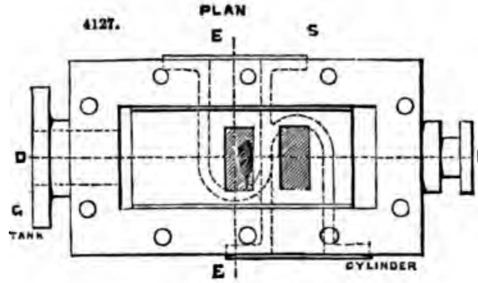


4122.



4127.

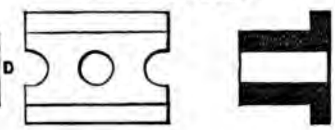
PLAN



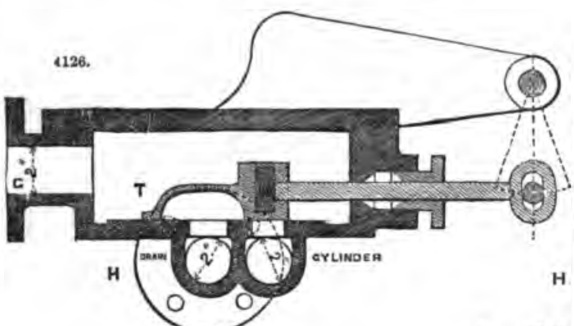
SLIDE VALVE AND CHEST

4128.

PISTON ROD GUIDE

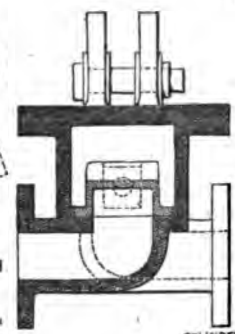


4126.



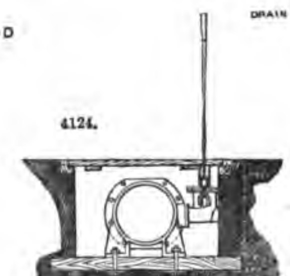
SECTION AT DD

4125.



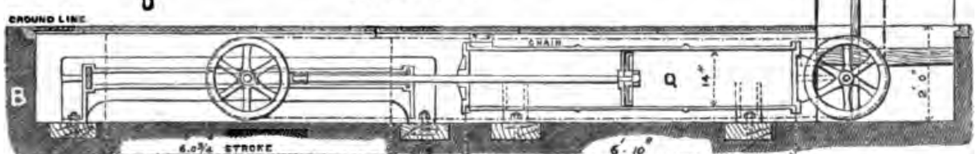
SECTION AT EE

4124.



SECTION AT CC

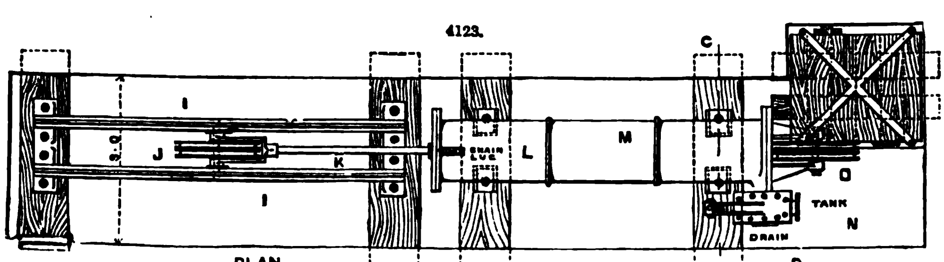
4122.



SECTIONAL ELEVATION

F

4123.



PLAN

methods of accomplishing the foregoing objects are illustrated. One of these methods consists in forming the suction-pipe of thin copper or other rapid heat-conducting metal or material for a portion of its length at M, immediately outside which another pipe or casing N is placed so much larger than the inner one M as to leave a steam space between them. The pipes are connected together so as to form a steam-tight chamber. The exhaust-steam pipe *m* from the steam-engine or from any vessel from which the steam to be condensed has to be discharged communicates with this chamber, which is kept constantly cold by the rapid circulation of the water passing through the suction-pipe M, and the steam is thereby condensed. An air-pump communicates with the chamber in this instance by means of the pipe *n*, as shown in section in Fig. 4120, for the purpose of working the condenser in the usual way. When the casing is placed sufficiently above the water level to enable the condensed water in the casing to overcome the force of gravity, or, say, more than 27 ft. of fall or height of column, the air-pump may be dispensed with, as the water will run away by its own gravity.

Another mode of applying this invention is shown at O, Figs. 4119, 4120. In this case the condenser is fitted to the delivery-pipe of the pump instead of to the suction-pipe as before, and illustrates a method of obtaining an increase of the condensing surface in a convenient way, and thereby shortening the length of pipe required for this purpose. The delivery-pipe O has two casings or pipes P Q fitted around it in a similar manner to that just described with respect to each other. To the inner chamber P the exhaust steam pipe *p* communicates, while the water in the delivery-pipe O is permitted to circulate freely in the outer chamber Q through the openings *q*. By this means both the inside and outside of the exhaust-chamber P is cooled by the water raised by the pump and discharged therefrom, and consequently the condenser may be made much shorter. The air-pump is in this case worked similarly to that above described, through the pump n^1. This double casing may be applied to the suction-pipe of a pump, and similarly the single casing may be applied to the delivery-pipe of a pump should it be preferred or found more convenient.

Hydraulic Lift of Alfred Davis, Sun Foundry, Leeds.—The annexed illustrations, Figs. 4122 to 4130, show a very simple and effective form of hydraulic lift, designed and constructed by Alfred Davis, of the firm of Hathorn, Davis, and Campbell. This hydraulic lift has been working for some time, and continues to work, in a most satisfactory manner.

The cylinder is fixed horizontally, and the stroke multiplied by means of pulleys, which at one end revolve in a bracket cast upon cylinder cover, and at the other work in a cast-iron cross-head, keyed to the piston-rod, and guided upon either side.

A chain is led round the pulleys running longitudinally over and under the cylinder, and after passing over the wheel A at the top of shaft, descends to the cage. The supply is drawn from a tank, and is admitted to the cylinder by means of a slide-valve worked with an ordinary lever, which serves the purpose of lifting, lowering, and regulating the speed of the cage.

This lift is single-acting, water being admitted on one side of the piston only; the weight of the cage being made sufficient to accomplish the down stroke. The water, having done duty in the cylinder, is allowed either to flow into the drain or run into a low-level tank to be used for other purposes.

The entire apparatus, with the exception of the cage and its immediate appendages, is enclosed and fixed in a trench below the ground level, and completely boarded over, so that space available for other purposes may not be lost; at the same time, care has been taken that every part shall be easy of access should the parts require inspection.

B, U, Q, F, R, A, Fig. 4122, is a sectional elevation. Q, piston; R, cage, of Davis' hydraulic lift.

I, J, K, L, M, Fig. 4123, is a plan. I, cross-head guide; J, pulleys; K, piston-rod; L, chain lug; M, cylinder.

Fig. 4124 is a section at C C of Fig. 4123.

H, Fig. 4125, is a section at E E of Fig. 4127. H, low-level tank or drain.

G, H, I, Fig. 4126, is a section at D D of Fig. 4127. G, supply tank; H, low-level tank or drain; I, slide-valve.

G, S, Fig. 4127, is a plan. G, supply tank; S, drain or low-level tank.

Fig. 4128 is of the piston-rod guide.

Fig. 4129 is of the valve-lever.

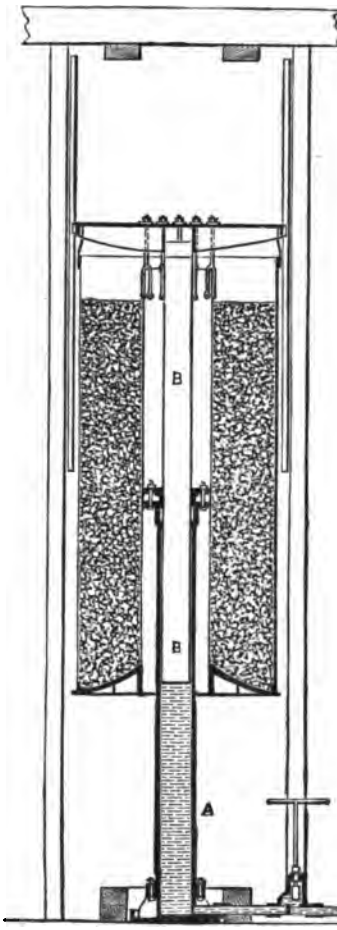
Fig. 4130 is of the shackle.

Armstrong's method of transmitting power by water pressure. Taken from the Proceedings Inst. M. E., 1868.—The most distinctive feature in this mode of transmitting power is the apparatus termed the *accumulator*, shown in Fig. 4131, which is so named because it accumulates the power exerted by the engine in charging it. It consists of a large cast-iron cylinder A, fitted with a plunger B, from which a loaded weight-case C C is suspended, to give pressure to the water pumped in by the engine. The accumulator is in fact a reservoir giving pressure by load instead of by elevation; and its purpose is to equalize the strain upon the engine in cases where the quantity of power to be supplied is subject to great and sudden variations. The load upon the plunger of the accumulator is generally such as to produce a pressure equal to that of a column of water 1500 ft. high, and the capacity of the cylinder is sufficient to contain the largest quantity of water which can be drawn from it at once by the simultaneous action of all the machines in connection with it. The accumulator also serves as a regulator to the engine, for when the plunger rises to a certain height it begins to close a throttle-valve in the steam-pipe, so as gradually to lessen the speed of the engine until the descent of the loaded plunger again calls for an increased production of power. From the accumulator the water is conveyed by a pipe to the various places where motive power is required; and in some cases where water is scarce it is returned by another pipe from the machines to the pumping engine to be again forced into the accumulator. The water thus acts merely as a carrier of power, and its function is consequently

the same as that of shafting used for conveying the power of a steam-engine to different parts of an establishment.

The question therefore to be considered is, in what respect or under what circumstances water pressure is superior to shafting for the transmission of power. It is not to be supposed that water pressure would be applicable as a substitute for shafting in mills and workshops where the machines to be driven are compactly grouped at short distances from the engine, and where they are generally continuous in their action. The superiority of water pressure is only realized in those instances where the machines to be put in motion are scattered over a wide area and are intermittent in their action, and also where the quantity of power to be transmitted is subject to great and abrupt variations. Upon an extended wharf, for example, every crane may happen to be in action at one moment, while at another time not one may be moving; and if shafting were used in such a case for conveying power to the cranes, the engine would sometimes be overtaxed and sometimes acting without any useful effect. But with water pressure as the medium of transmission, the variation of work is met by the accumulator; and the engine acts always under a uniform load, storing up its surplus power at times when the whole is not transmitted. Moreover, the ramifications readily carried out in laying water-pipes are not practicable with shafting, nor can shafting be extended beyond very limited distances.

4131.



Water pressure also possesses the advantage of communicating to machinery a much more controllable and adjustable motion than shafting. The water can be gradually turned on or shut off, and can be admitted as quickly or as slowly as may be desired; while with a shaft the motion acquired is sudden and cannot be communicated gradually. Another advantage of the hydraulic system is that the pipe conveying the water is itself at rest, and does not suffer any appreciable wear nor require any attention; whereas a shaft being in motion is attended with friction and consequent wear, and involves constant lubrication.

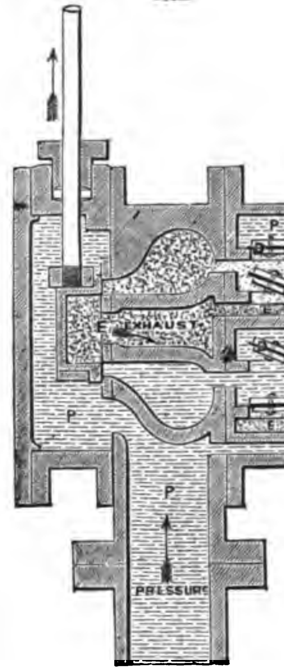
The absence of elasticity in water gives great steadiness and precision to the movements of machines actuated by water pressure; but on the other hand, water being incapable of expanding like steam in a cylinder, the quantity expended is not proportionate to the load. Thus a machine propelled by hydraulic pressure measures off the same quantity of water, whatever may be the resistance overcome; and therefore when the machine is inadequately loaded the expenditure is more than equivalent to the effect produced. This loss of power may in a great measure be obviated by making the machines with variable powers; but the simplicity of single-power machines renders them preferable in many cases, notwithstanding their greater expenditure of power. In fact, for the purposes to which water pressure is most usually applied, safety, simplicity, and general convenience are more to be considered than economy of power, because owing to the intermittent character of the work the required quantity of power is not large in the aggregate. It has also to be recollected that, although power is sacrificed by that very property in water which gives so much steadiness and safety to its action, yet the favourable condition under which a steam-engine works when pumping against a constant head, as in charging an accumulator, cheapens the production of the power, and compensates for its more lavish application.

In connection with the non-elastic character of water, it will be observed that its incompressibility in the cylinder of the machines would, if not provided against, cause very injurious shocks and strains to the machinery, by suddenly arresting the momentum of the moving parts on the closing of the outlet passages. To obviate this liability, nearly all varieties of water-pressure machines adapted for rapid action require the introduction of what are termed relief valves. These will be fully described in our article on VALVES; and it is therefore only necessary on this occasion to describe them as consisting of small clacks D D, as shown in Fig. 4132, opening against the pressure P in the supply-pipes, and yielding to any back pressure on the piston that exceeds the accumulator pressure. In the drawing P P represents the pressure, and E E the exhaust-passages.

With a pressure equal to a column of water 1500 ft. high, the loss of head by friction in the pipes forms a very inconsiderable deduction from the entire column; and the pressure may therefore be conveyed without any serious sacrifice to great distances from the engine. In some instances the length of the pressure pipes has been extended to more than two miles without any apparent decrease of effect; but in all cases where the pipe is very long it is desirable to apply an accumulator at each extremity, in order to charge the pipe from both ends. The most advantageous

pressure of water for practical use seems to be that mentioned above, namely, 1500 ft. or about 700 lbs. a square inch. By increasing the pressure the size of the pipes and of all parts of the apparatus is lessened; but on exceeding the above limit a difficulty begins to be felt in preventing leakage and keeping the valves and packings in order; and this objection more than counterbalances the advantage of reducing the size of the apparatus.

4132.



Compressed air has often been proposed, and in some instances tried, as a medium for the transmission of power. Being elastic it has an advantage over water in accommodating its volume and consequently its expenditure to the load on the piston; but on the other hand it does not give back all the power put into it by the engine, because practically it cannot be used expansively to the full extent of its previous compression. In order to return all its acquired power, the air must undergo no throttling, and must be discharged from the cylinder in which it acts at the density of the atmosphere; and as these conditions are impracticable, the loss from elasticity in air is probably as great as that from the absence of elasticity in water. But the use of compressed air is subject to a far more serious source of waste by leakage, which in the case of air is very difficult to detect; and in an extended system of pipes and machines, requiring a multitude of joints, valves, and fitting surfaces, the leakage of the air must form an insurmountable difficulty. Moreover, the elasticity of air deprives the machines to which it is applied of that perfect steadiness and precision which is afforded by the incompressibility of water. Nor is any advantage to be gained by adopting the converse process of exhausting the air instead of compressing it, since the difficulties which apply to the one case are equally incident to the other.

The purposes to which water pressure has been applied as a means of transmitting power are numerous; in fact in almost every case where manual labour is used as a mere motive power it may be superseded by engine power transmitted by means of water pressure. The widest application of this system is in docks, where the water-pressure machinery is now most extensively used in England for the purpose of opening and closing the gates, swing bridges, and sluices, and also for hauling ships through the locks and discharging and warehousing cargoes. It is also very generally employed in the various operations connected with the shipment and discharge of coal; and the mechanical arrangements applied to meet the different conditions under which these operations have to be performed are very various, and in some cases necessarily very elaborate. Perhaps the case of greatest novelty in this branch of the application of water pressure is that of a machine erected for the purpose of shipping coals at Goole Docks, on the river Humber, where barges containing 32 tons of coal are floated into a cradle, and then lifted bodily to a considerable height and turned over into a shoot, which delivers the coal into a ship alongside.

In France it is in use at Marseilles, at Rouen, and at the goods station of the Paris and Lyons Railway in Paris, for the purpose of loading and unloading the wagons, and also for hauling them in the station yard. The machinery at this station affords a good example of the application of the principle to railway goods traffic, and may therefore be selected for description.

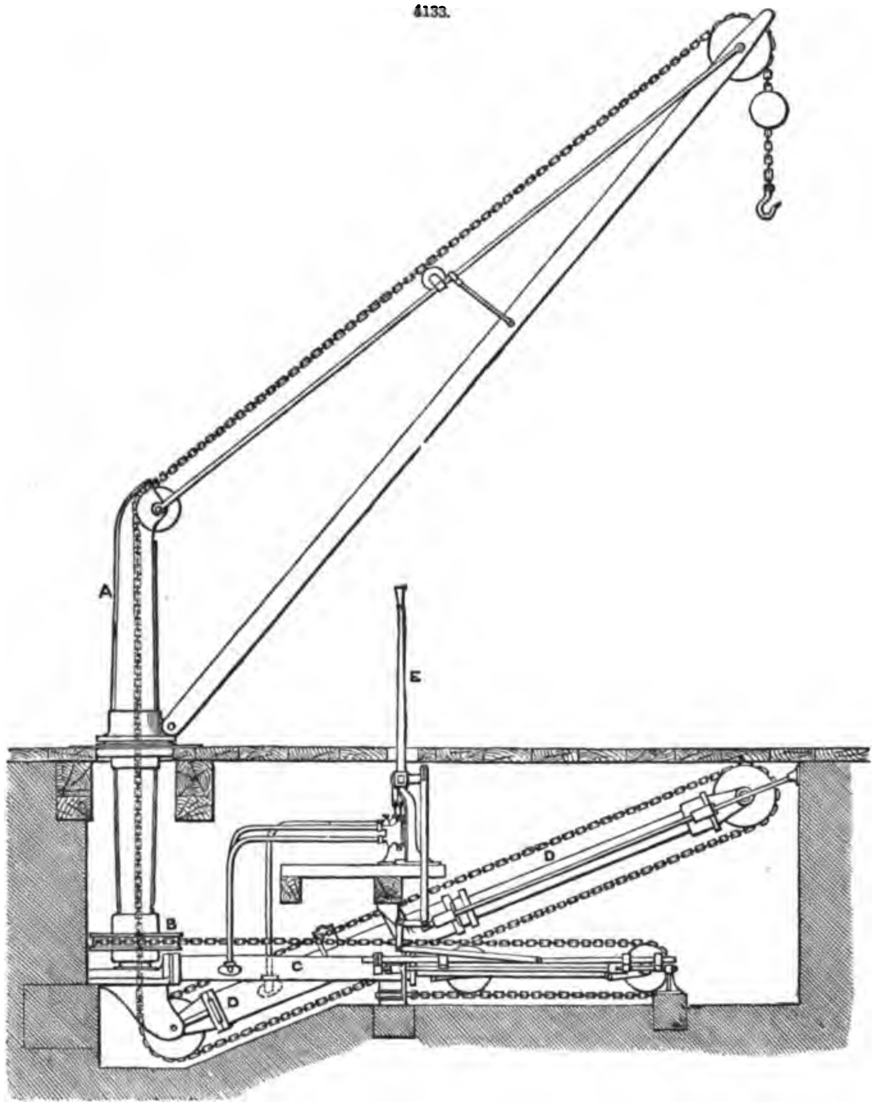
The machines comprise fifteen single-power hydraulic platform cranes to lift $1\frac{1}{2}$ ton; and three double-power similar cranes to lift $1\frac{1}{2}$ ton with the lower power, and 3 tons with the higher power; also two hydraulic engines for driving capstan-heads for hauling trucks.

The single-power cranes are represented in Figs. 4133, 4134. They are adapted to turn as well as to lift and lower by the water pressure. The jib is a fixture to the crane-pillar A, which is made to revolve by means of a chain passing round the cupped wheel B, and worked by a pair of hydraulic presses C C. The diameter of the ram of each turning press C is 4 in., and the length of stroke is 3 ft. 8 in., which is doubled by passing the chain over a pulley at the end of the ram and fixing the extremity to the cylinder. The ram of the lifting press D is $5\frac{3}{4}$ in. diameter, and has a stroke of 4 ft. 8 in., and the motion is multiplied four times by means of pulleys. The chain is conveyed upwards through the centre of the pillar A, and thence over the end of the jib. The lifting cylinder D is placed at an angle, to facilitate the overhauling of the chain. The valves for lifting, and lowering, and for turning, are slide-valves, the lifting and lowering valve having two ports, and the turning valve three ports. Each valve is worked by a lever E passing through the platform, the two levers being placed at a proper distance apart, so as to be worked by a man standing between them with a hand on each lever. To provide against the crane-jib slewing round beyond the range of the turning presses, the turning valve is made to close by a self-acting arrangement at each extremity of the range.

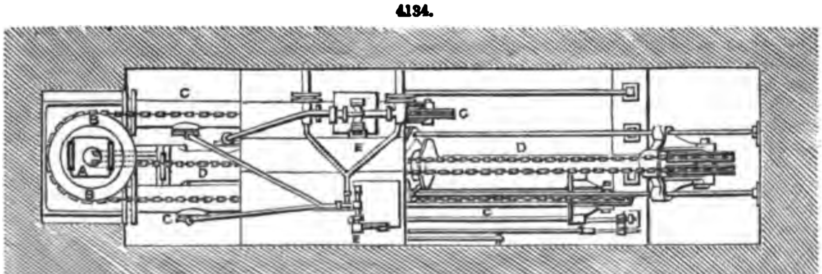
The double-power crane is of the same general construction as the single-power; but instead of a simple hydraulic press with ram for lifting, a bored cylinder with a combined ram and piston is applied, as shown in Figs. 4135, 4136. For the lower power the pressure is admitted upon both sides of the piston A, and therefore virtually acts only upon the ram B, which is half the area of the piston. For the higher power the front side of the piston is open to the exhaust E, leaving the pressure P to act on the back only, and the effect is then proportionate to the area of the piston,

which is twice that of the ram. This alternative action is determined by the intervention of an extra valve C, Figs. 4135 and 4137; when this valve is opened, as shown in Fig. 4137, the pressure

4133.



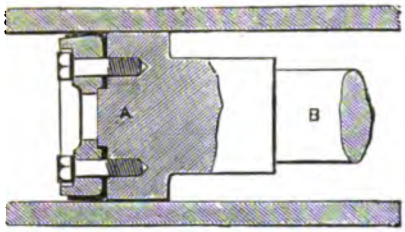
4134.



P has access to both sides of the piston, and the lower power is then obtained; while for the higher power the valve C is closed, and the exhaust-valve D is opened, whereby the front side of the piston is kept constantly open to the exhaust E. In cases where three powers are required, three

simple hydraulic presses are commonly used, which act either singly or in combination; but the same effect may be obtained with a bored cylinder and piston combined with two concentric rams,

4136.

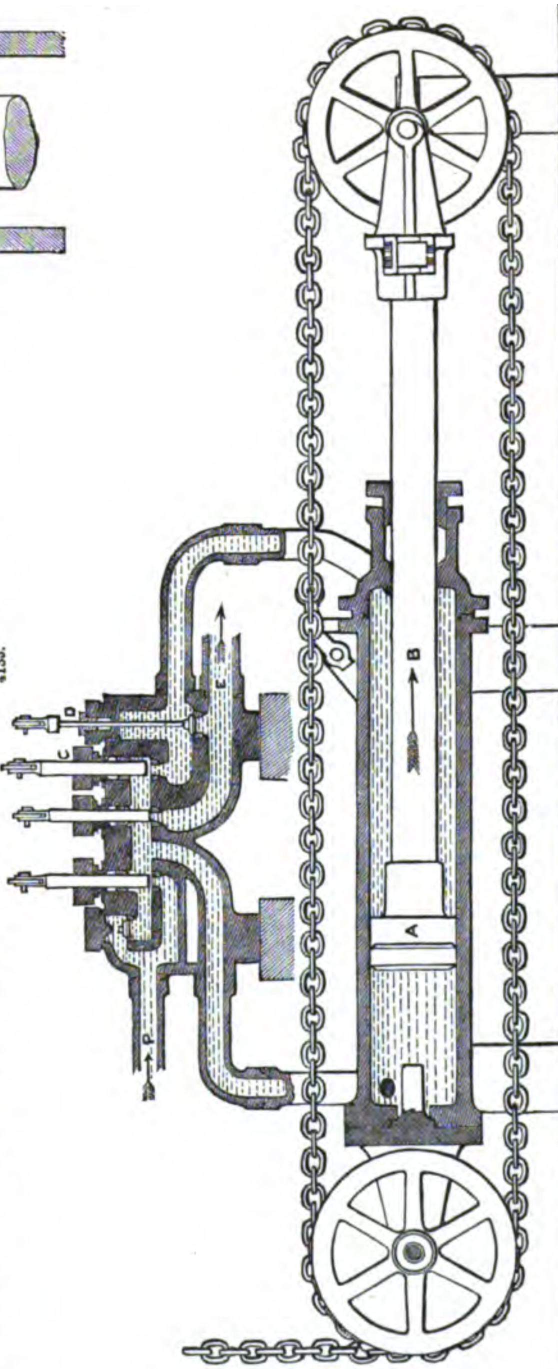


the external ram being secured by a pawl when its action is not required, and the internal ram acting through a water-tight gland in the outer ram. In this case the lowest power is obtained by admitting the water only on the front side of the piston, whence it enters into the interior of the larger ram through a hole near the piston, and forces out the inner or smaller ram. The second power is obtained by admitting the water to both sides of the piston; and the highest power is brought into action by opening the front side of the piston to the exhaust, while the pressure operates on the back of the piston.

The capstan engines used at this railway station have each two oscillating cylinders with combined rams and pistons, working cranks at right angles; on the front side of the piston, which is half the entire area, the pressure is constant, and the back communicates alternately with the pressure and the exhaust. The engine therefore acts by a difference of pressure in one direction, and by a positive pressure in the other, the effective pressure being equal in both cases; and the action is governed by a two-port slide-valve worked direct from the trunnion. In these engines, as well as in the cranes, relief valves are applied to prevent concussion from the water shut in.

Since the platform cranes of the Paris and Lyons Railway were constructed, a new arrangement of platform crane has been introduced, in which the lifting cylinder is arranged so as to form the crane-pillar. An example of this kind of crane is shown in Fig. 4138, where A is the lifting ram acting upon a chain B, which gives a twofold motion to a double-pulley running block C. A corresponding double-pulley block D is fixed to the base of the jib, and over these pulleys the lifting chain passes four times, so that the range of the ram is multiplied altogether eight times at the outer end of the chain.

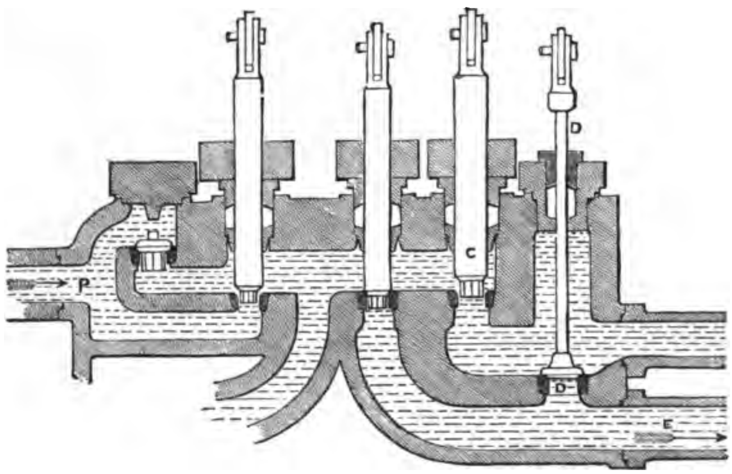
4135.



Another modification of the same kind of arrangement is exhibited in Figs. 4139, 4140, where the crane-pillar is carried in top and bottom bearings, and the lifting press A is placed between

he two cheeks of the pillar. In this case there is no turning power, and the lifting valve B, as well as the press, is attached to the crane-pillar, as shown to a larger scale in the section, Fig. 4141.

4137.



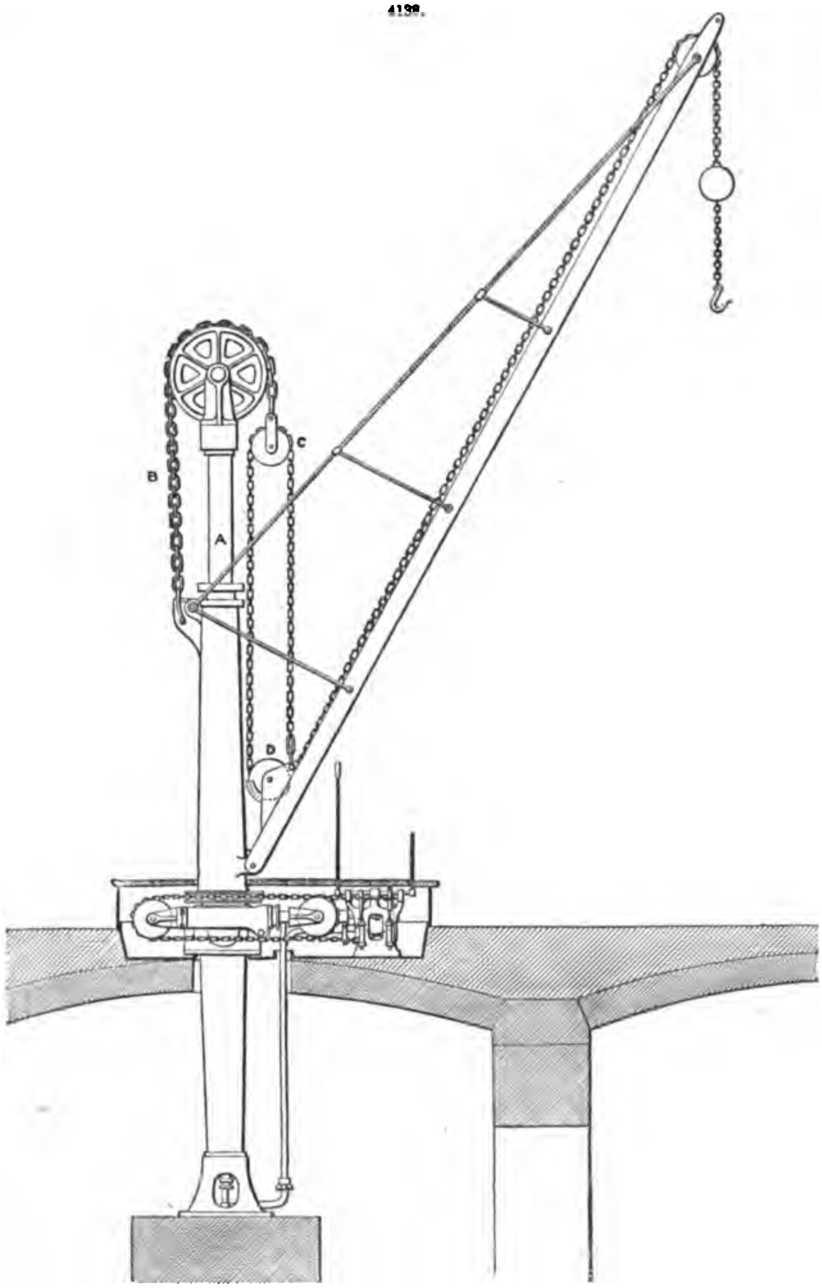
This is the simplest and cheapest form of hydraulic crane which is made. In all cases of cranes containing the lifting press in the pillar, the water is admitted through the pivot at the bottom, which is made water-tight by means of a cupped leather. For cranes of a very high power, where only slow motions are required, it is now usual to employ the ordinary gearing of a steam-crane, and to apply the water pressure by means of a small hydraulic engine fixed in the framework of the crane.

Hydraulic cranes have of late years been introduced with great advantage at the Elswick Works, both in the forge and in the foundry. In the forge they are applied to the service of a 12-ton hammer, and by this means forgings ranging in weight up to 20 tons are manipulated under the hammer with perfect precision and great saving of time and labour. In the foundry they are so applied as to command every part of the floor, and thus wholly to supersede manual labour for every purpose of lifting and carrying. The form of crane used in each of these departments is the same, and is represented in Figs. 4142, 4143. The jib and pillar of the crane are of wrought iron, and revolve in top and bottom bearings. The crane has three motions, namely, lifting, turning, and traversing, all of which are effected by hydraulic power. The lifting cylinder A is made of double power by the ram and piston arrangement before described, the highest power being equal to 20 tons; the ram is 11 in. diameter, and the piston 15½ in. diameter, the length of stroke being 6 ft. 8 in. The turning cylinders B are applied in the usual manner at the foot of the crane-pillar, the rams being each 4½ in. diameter, with 5-ft. stroke; and both the lifting and the turning cylinders, with their valves, are fixed in a chamber beneath the level of the floor. A three-port slide-valve is used for the two turning cylinders, and mitre-valves for the lifting cylinder. The chain from the lifting cylinder is carried upwards through the crane-pillar, bending over a sheave C at the top of the pillar, and passes successively over the pulleys of the travelling carriage D and the running block E, and is finally made fast at the extremity F of the jib. For the purpose of overhauling the ram of the lifting press, a small press is placed between the two turning presses B; and the overhauling action is effected by a chain and sheaves multiplying four times, the outer end of the chain being attached to the sliding head of the lifting ram at I. The pressure in the over-hauling press is constant, and its action is therefore equivalent to that of a counterweight; the ram is 4½ in. diameter, with 3 ft. 5 in. stroke. For effecting the traversing motion of the load suspended at the hook G, the travelling carriage D is hauled inwards and outwards by two presses H fixed to the back of the crane-pillar, and connected by chains with the travelling carriage; the ram of each press is 5½ in. diameter, with 4 ft. 7 in. stroke. The alternating action of these presses, which is precisely the same as that of the presses B used for the turning motion, is regulated by a three-port slide-valve K attached to the front of the pillar, with a lever at each side for working it. The water is supplied to, and discharged from, these presses by two pipes which pass through the top bearing of the pillar, and the connection between the valve and these pipes is effected in each case by a trunnion joint at J J.

Another novel purpose to which hydraulic pressure has recently been applied is the raising of the materials required for feeding blast furnaces. The great increase in the height, size, and productive power of modern blast furnaces has necessitated a great increase of speed and power in the lift; and the employment of water-pressure machines has fully satisfied these requirements. The apparatus employed for this purpose is represented in Fig. 4144. The framework of the hoist is constructed of cast-iron columns supported by wrought-iron bracing. Two guided cages A A are used for receiving the barrows containing the materials to be raised to the furnace mouth; and two separate lifting-presses B B, one for each cage, are fixed in an inverted position against opposite sides of the framing, the ram of each press being 11½ in. diameter with a stroke of 8 ft. The lifting chain makes five turns over the pulleys C C of each press, so as to multiply the stroke ten-fold, and is carried up over a sheave D at the top of the framing, and thence descends to the cage

to which it is attached. The two cages are connected with each other by a wire rope which passes over a sheave E at the top of the framework, so that they balance each other, the one being lowered

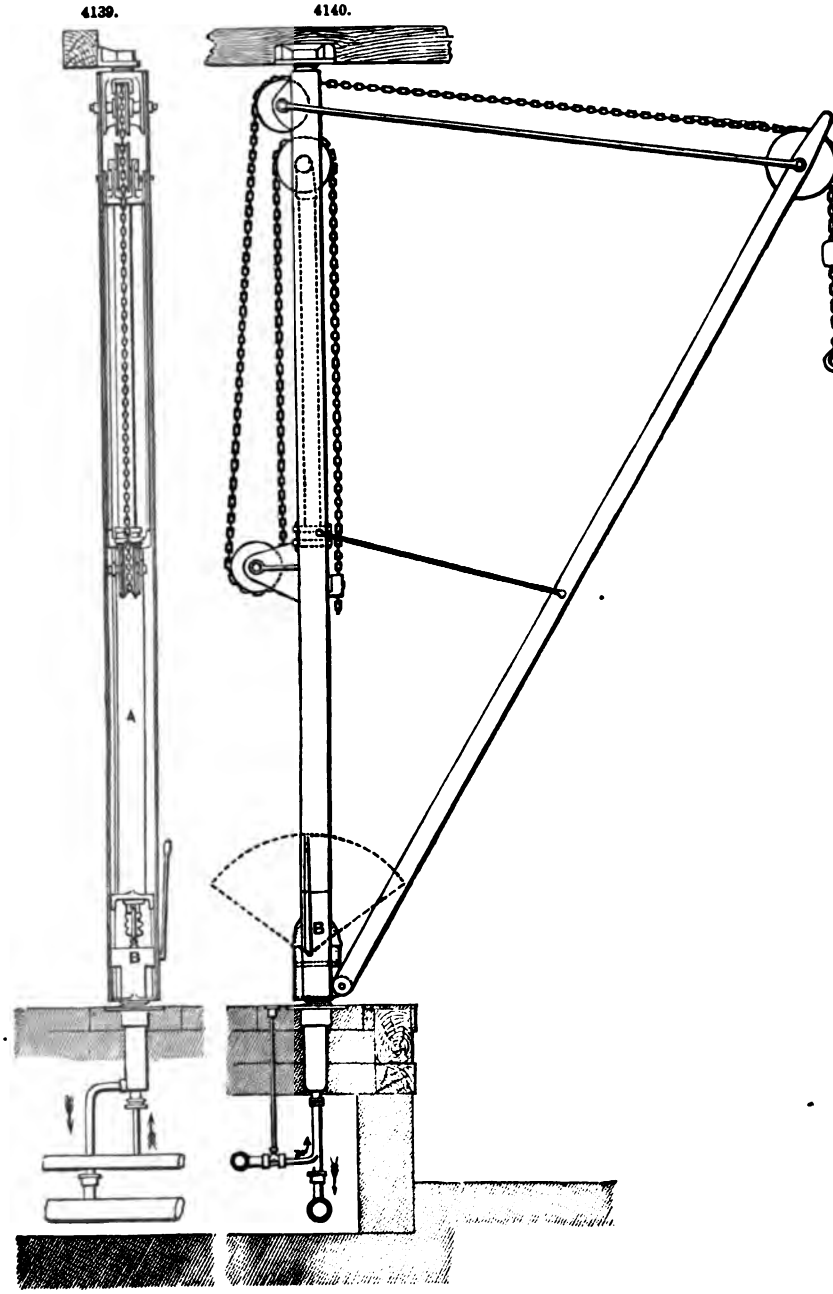
4138.



while the other is raised. The cages lift two barrows at a time, weighing with their contents 1¼ ton, and they are hoisted to the top at the rate of 4 ft. a second; a much higher speed could be attained by increasing the size of the valves and pipes to the required extent. A three-port slide-valve is used for working the two presses, and admits the water to the one press while it discharges it from the other. The valve is worked at the bottom, but a rope is provided to enable it to be worked from the top as well. An arrangement is applied by which the cages gradually close the valve at the termination of each lift, and thereby ensure a soft and gradual cessation of the motion; and a safety apparatus is attached to each cage, to arrest its fall by gripping the guide bars in the event of the breakage of a chain.

When this paper was read, R. Mallet observed that it was a remarkable circumstance that Bramah, the inventor of the hydraulic press, had suggested as early as 1802 the application of the

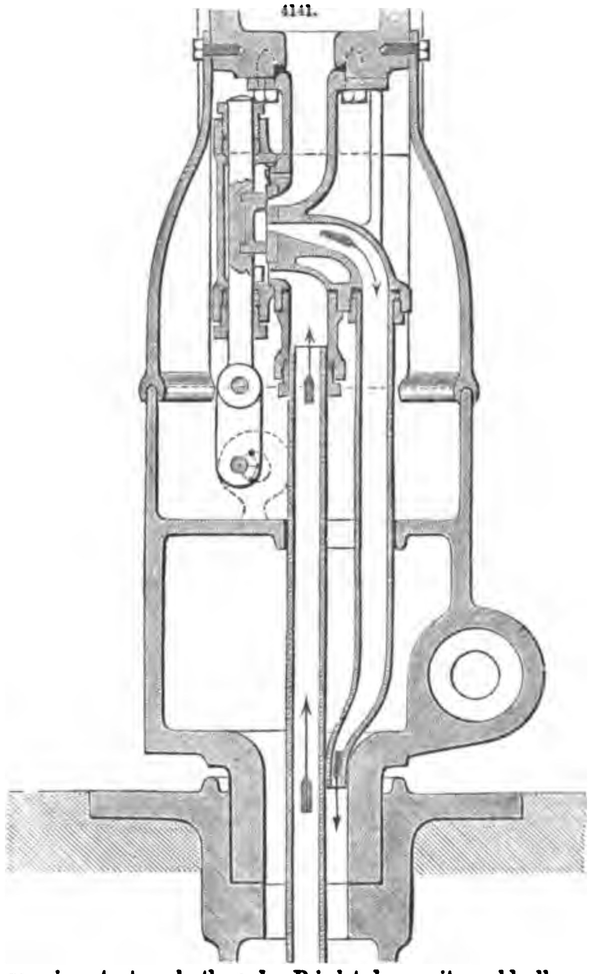
4139. 4140.



same principle for working the cranes on the dock quays at Dublin and in the warehouses of the London Docks, as was shown by the accompanying autograph letter. Extract from autograph letter of Joseph Bramah to Robert Mallet, dated London, 10th Nov. 1802, the original of which was shown to the meeting;—"I have also now applied it" (the hydraulic press) "with the most surprising effect to every sort of crane for raising and lowering goods in and out of warehouses. So complete is the device, that I will engage to erect a steam-engine in any part of Dublin, and from it convey motion and power to all the cranes on the keys and elsewhere, by which goods of any weight may be raised at one-third of the usual cost. This I do by the simple communication of a pipe, just the same as I should do to supply such premises

with water. I have a crane on my own premises which astonishes every person to whom it has been shown, as they see the goods ascend and descend fifteen or twenty times in a minute to the height of 18 or 20 ft., and at the same time it is impossible for any person unacquainted with the principle to discover how or where the power comes from." This showed that Bramah had distinctly seen the great scope for future expansion of the principle; but he had been too much in advance of the time for his ideas to be practically developed during his lifetime to so great an extent as they had since been by the very ingenious and perfect arrangements of Sir William Armstrong described in the paper now read.

4141.



Hydraulic Rams.—The hydraulic ram, the principle and mode of action of which every engineer is acquainted with, is employed solely for the purpose of raising water. See Fig. 93, p. 35. It may therefore be classed among pumps; but as it utilizes for this purpose a volume of water falling from a certain height, that is, a fall of water, it must also be considered as a *hydraulic motor.*

We shall not describe here the classic ram of Montgolfier, with which everybody is acquainted: but we will at once examine the improved ram by M. Bolée, of Le Mans, which was exhibited in Paris in 1867. This ram, represented as a whole and in detail in Figs. 4145 to 4153, is nothing but Montgolfier's ram provided with certain details which give it a regular and permanent action and enable it to work without being constantly attended to.

The motive water arrives through the pipe A, and the water raised is forced into the reservoir of air D, whence it flows up the ascension-pipe. When the ram is not at work, the valve B is let down; it would allow a passage to the water if care were not taken to place a hatch at the head of the conduit which brings the water to the body A of the ram. Suppose this hatch opened, the water puts itself in motion in the conduit, and the ram begins its action, presenting successively and periodically the three following phases:—

First phase.—The water that arrives through the inlet-pipe begins to flow with a velocity due to the height of the fall, through the valve B (which is let down), and through the spaces between the four arms *t* of the upper guide of this valve, Fig. 4148; but the flow of the water and the pressure exerted by it while in motion upon the lower face of the valve, causes this latter to close, and the issue of the water ceases.

Second phase.—At the moment when the issue of the water ceases, the *vis viva* possessed by the column of water in motion causes the *ramming stroke*, that is, opens the retaining (or forcing) valve G; the water enters the air-vessel D, and at the same time, in consequence of the effect of the shock upon the valve G, and in virtue of its elasticity, flows back through A.

Third phase.—At the moment when the backward motion begins, the valve G closes and B opens, again allowing a passage to the water coming from the upper water-course; then the three phases begin over again.

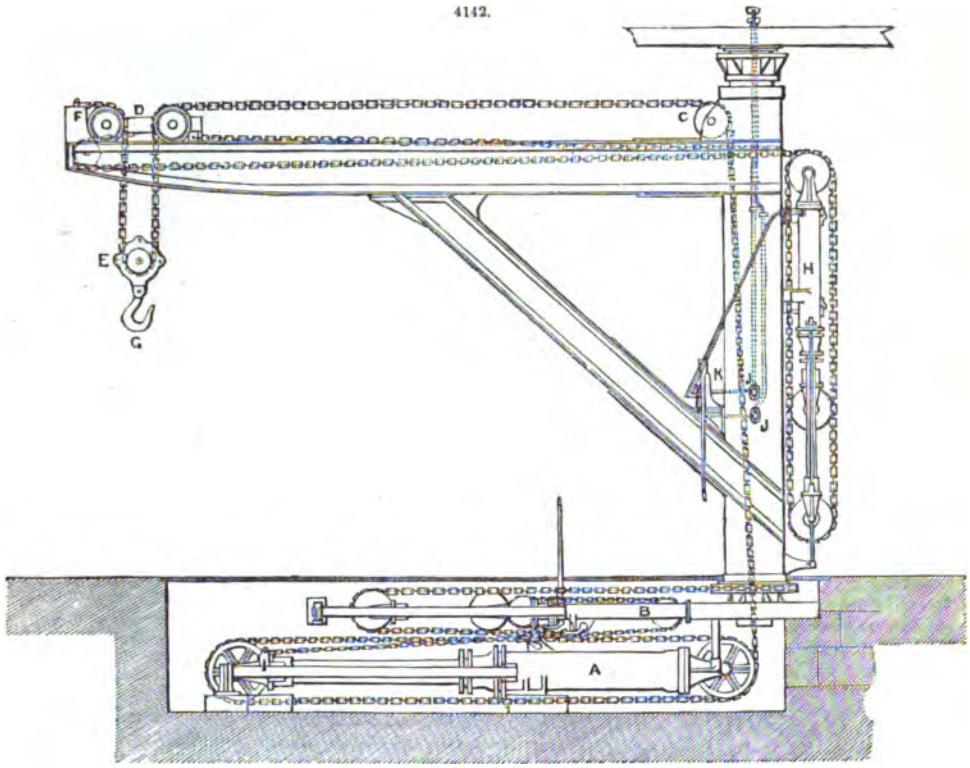
Having explained the action of the ram, we have only to describe the details of its construction.

The valve B is partly balanced by a counterpoise *e*, to which it is connected by means of a rod *b*. The effect of this addition, which does not exist in Montgolfier's ram, is to make the valve B close more readily. The lower rod of this valve is guided, as shown in Fig. 4148, in a little cylinder with two lateral openings, the bottom of which is furnished with india-rubber washers. Consequently the valve on falling strikes easily and noiselessly against its lower stop.

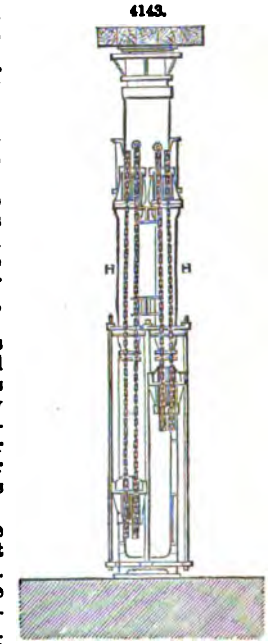
To ensure the proper action of the ram, and to prevent a breakage either in the inlet or in the

outlet pipes, an indispensable condition is that the reservoir D constantly contain a sufficient quantity of air. But in Montgolfier's common ram the reservoir is supplied by a *snifting valve* placed

4142.



4143.



upon the body of the ram: the consequence of this is that in wet seasons the water rises above this valve, and as the supply of air is cut off, there is danger of a breakage occurring.

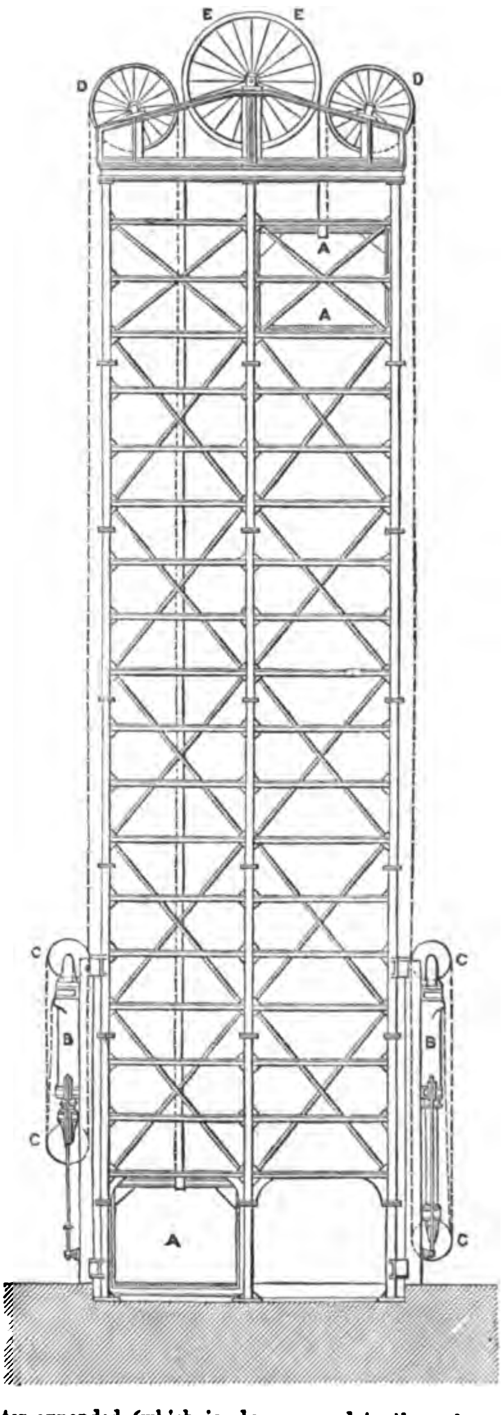
This defect M. Bolée has removed in the following way;—In front of the valve B he places a long, vertical, hollow column *e*, Figs. 4145, 4146, the top of which is high enough to be out of the reach of the highest floods. The details of the head of this column are shown in Fig. 4151. It is furnished with a snifting valve, the opening of which is regulated by the pointed screw *m* and a retaining valve *s*; a pipe *e'* forms the communication between the chamber of this valve and the body of the ram; the pipe opens into the ram below the clack G at E', Fig. 4145, and its orifice is furnished with a second valve *s'*, the details of which are shown in Figs. 4152, 4153. At the moment when the stroke occurs below the valve G, the water ascends violently the column *e* and compresses the air contained in it; a portion of this air escapes through the snifting valve, but the remaining portion lifts the valve *s*, and occupies a position above.

When the valve B descends, and the water entering the ram flows through the orifices of this valve, the water descends in the column *e*, and the external air enters through the snifting valve. The valve *s'* prevents the compressed air surrounding it from returning into the pipe *e'*, by closing the orifice of this pipe under the action of the stroke. The compressed air contained in the chamber of this valve is then forced to enter under the clapper G at the moment when the latter is open, and this air rises up into the air-vessel D. Thus the supply of air to this vessel is effected at each stroke.

It is obvious that the importance of the mass of water contained in the ram, from the commencement of the inlet-pipe up to the clapper G, is not unworthy of consideration from the point of view of the effect produced. No authoritative rule exists relative to this question. According to some writers, the length of the body of the ram, that is, the length of the inlet-pipe, should be about $\frac{3}{4}$ of the height to which the water is to be raised. According to others, this length should be equal to the height, increased by the ratio between the double of the height and that of the fall. But neither of these empirical rules are in accordance with the dimensions of various existing rams.

As a mean, it may be reckoned that in a well-constructed hydraulic ram, the work, that is, the proportion of effective work in water raised to the motive work expended, is 60 per cent. This is a result that is not easily obtained with the best hydraulic motor working the best system of pumps. But the hydraulic ram can be constructed for only very small forces: were it not for this fact, this very simple engine would be generally employed.

4144.



Leblanc's Ram.—We will conclude our remarks on hydraulic rams with a few words respecting a contrivance employed to draw water from an excavation.

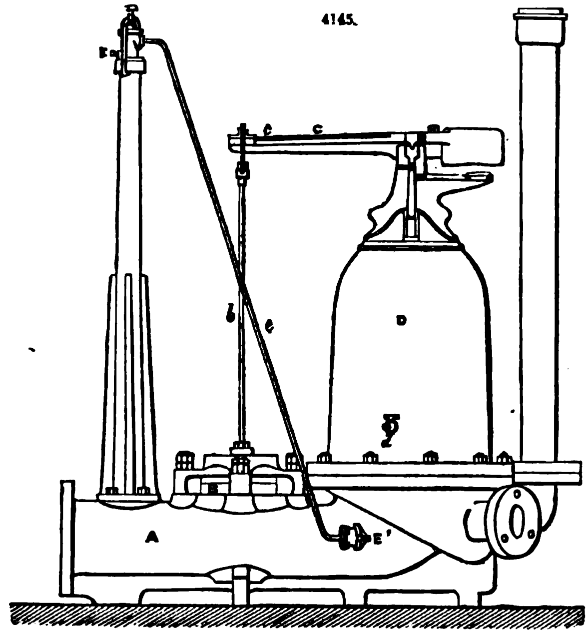
When the quantity of water to be drawn up is small, it is well to utilize the fall itself upon which hydraulic works are executed to effect the clearing of the excavation.

Fig. 4154 represents a hydraulic ram contrived for emptying a place of water. Two valves S S are connected by a beam oscillating about an axis *o o*. The water of the upper course, by flowing through the aperture uncovered by one of the valves, produces the effect of the water-spout, and sucks up the water from the stream to be emptied through the pipe *n n*. This pipe is provided with an air-vessel *m*, and separates into two branches S' S', furnished with retaining valves; each of these two branches opens under the seat of one of the valves S S. The water sucked up flows away into the lower course, with the motive water, through one of the pipes *d d*. The flow of the motive water through one of the valves S causes this valve to close, and consequently the other to open, and *vice versâ*. Thus the apparatus is self-acting.

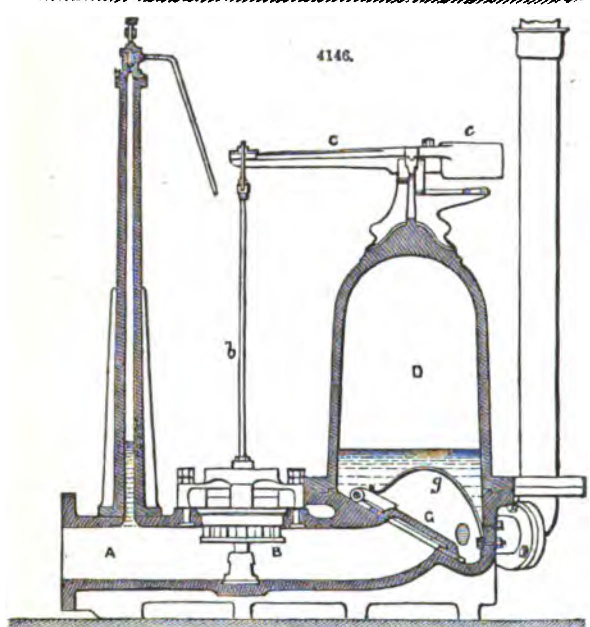
The hydraulic ram was used in making the Mont Cenis tunnel to compress the air necessary for the supply of the wind-ways and for working the boring tools. Before the erection of the powerful compression-pumps used later, M. Sommalier, the engineer of these works, had a series of hydraulic rams constructed working under a fall of 26 mètres. These rams compressed up to five atmospheres the air necessary to drive the tools and to ventilate the works.

Water-pressure Engines.—This class of motors is generally erected to utilize small volumes of water and very high falls. They are usually employed to raise water or rather to drive pumps. In this case it consists, in its essential parts, of a cylinder and a piston moving with a reciprocating motion; the piston-rod transmits this motion directly to the pump. It will be seen at once that the construction of water-pressure, or as they are usually called, reciprocating engines, is much more like that of steam-engines than that of the hydraulic motors which we have already considered. These pressure engines, however, require a particular arrangement of the distributing apparatus, often giving occasion for some very ingenious and remarkable contrivances, which we will describe farther on. Two artifices used to vary the pressure in a steam-engine, namely, *expansion* and *variation of pressure*, cannot be employed in a water-pressure engine. The water being incompressible cannot expand, and if the pressure were made to vary, the utilized fall would be diminished without proportionately reducing the volume of water expended (which is always equal to the volume generated by the piston); therefore the duty of the engine would be decreased, which would be bad. The variations of the fall, and consequently of the pressure, should be only an inappreciable fraction, so to speak, of the total fall; for this reason, these engines are applied only to high falls.

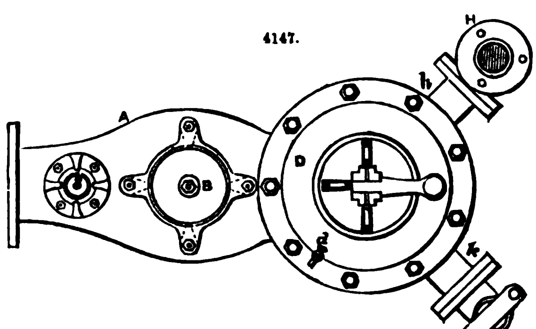
4145.



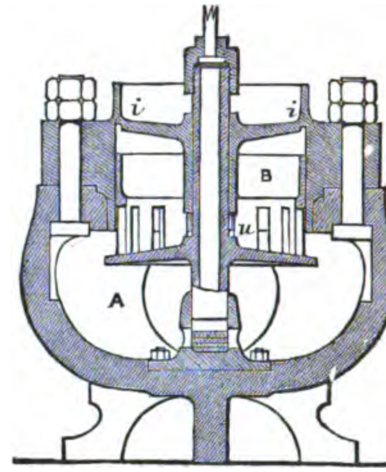
4146.



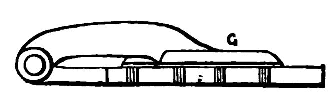
4147.



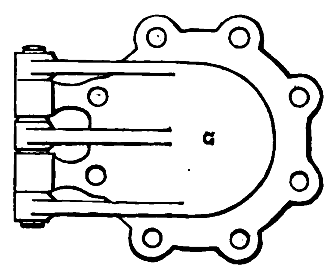
4148.



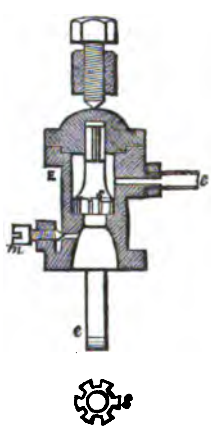
4149.



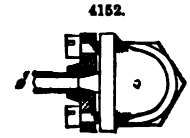
4150.



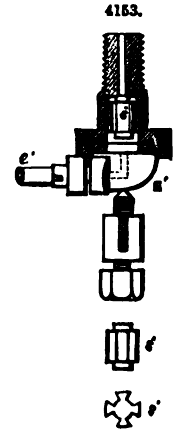
4151.



4152.

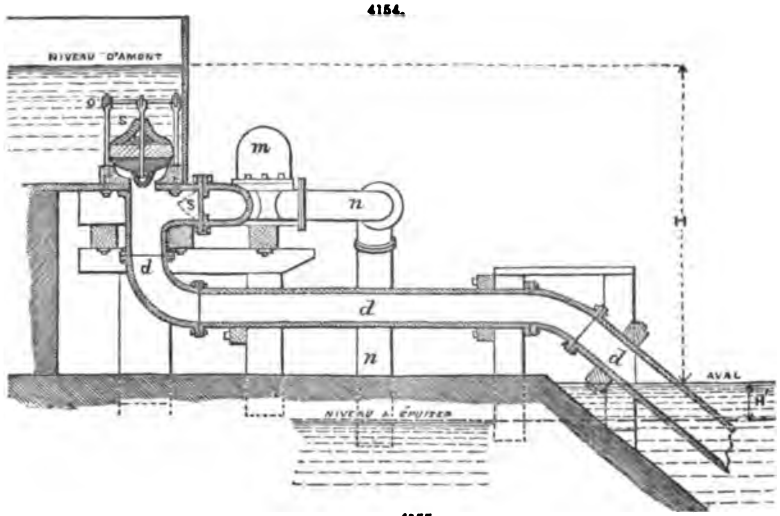


4153.

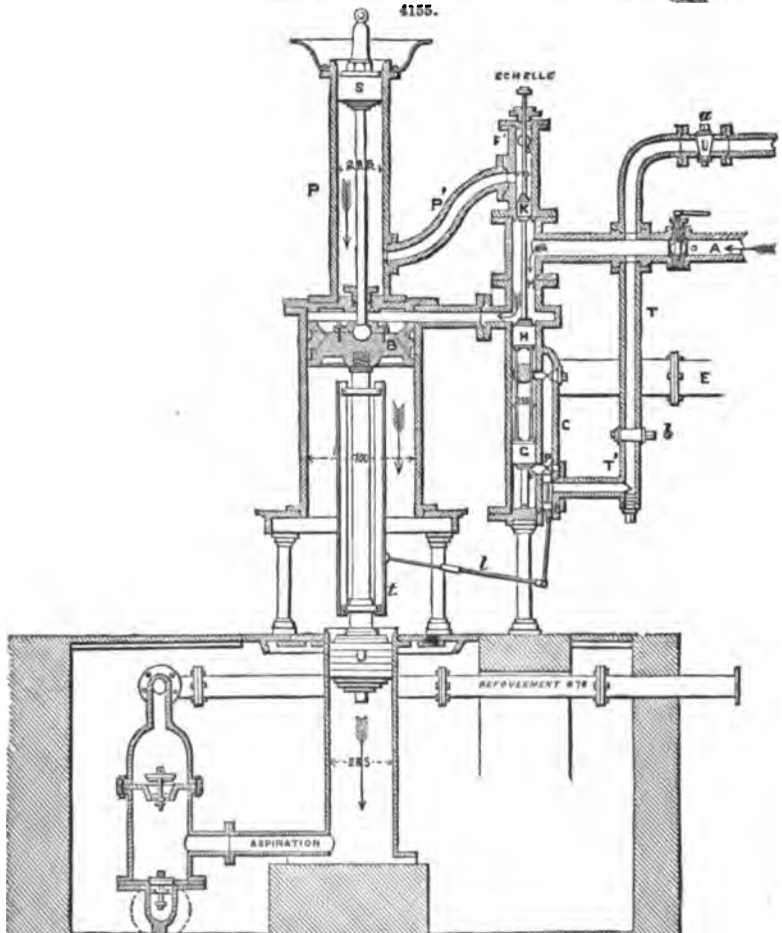


M. Girard has, indeed, studied their application to low falls, but the motion has not been received in practice.

4154.



4155.

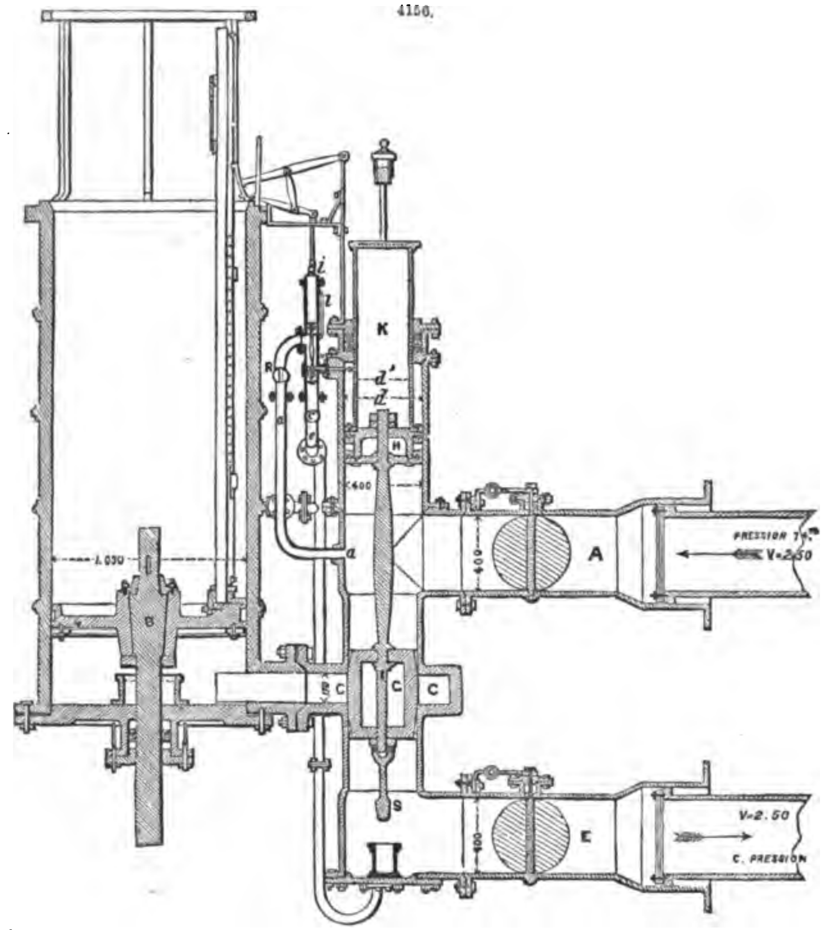


With respect to the mode of action of the water, these engines are divided into two classes: single-action and double-action engines; the former are vertical, the latter horizontal. Direct and

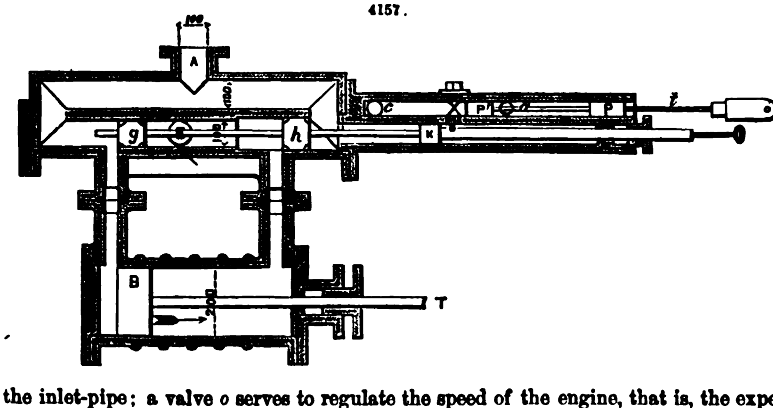
single-action reciprocating engines work either with a downward or with an upward stroke. In the former case, the motive water is let in only upon the upper face of the piston; in the latter case, it is let in only beneath its lower face.

Reichenbach's engine at Illsang, in Bavaria, is the oldest and most remarkable type of the single-action engines, working with a downward stroke. Fig. 4155 represents a vertical section of this engine. For the sake of brevity, we will merely give an explanation of the references.

4155.



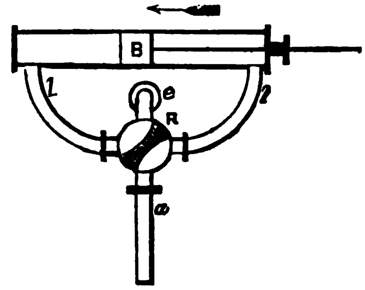
4157.



A, the inlet-pipe; a valve *o* serves to regulate the speed of the engine, that is, the expenditure of water. This expedient is serviceable where there is an excess of fall, but it is bad in principle,

as the partial closing of the valve causes a contraction. a, air purge-cock; when this is opened before the engine is started, the cock b is shut, and when the engine is cleared of air, the cock a is closed and b opened. E, outlet or discharge pipe for the water that has done its work; in the figure, the communication between this pipe and the cylinder is interrupted by the piston H, and the communication between this same pipe and the cylinder C established.

4158.



At starting, the driving or loaded piston B being at the top or beginning of its stroke, the mutually dependent pistons K, G, H, are raised so that the piston H may occupy the position H′. The pistons p and p' are moved by hand, and the orifice o is uncovered to put it in communication with the discharge-pipe E. The diameter of the piston K is a little less than that of the pistons H and G, which are equal, and the top of this piston is in communication with the motive water through a pipe which opens at o'. The valve O being open, the pressure of the water causes the three pistons K, H, G, to descend, and the piston H uncovers the orifice of communication with the driving piston B; these three pistons then occupy the positions shown in the figure. As the piston S, which is in constant communication with the motive water through the pipe P′, is of a much smaller diameter than the loaded piston B, the latter descends, and brings down, consequently, the piston u of the pump; this piston forces the water to be raised up the ascending pipe.

A little before the piston B has reached the end of its stroke, a pin t acts upon a lever l, which raises the pistons p and p', and places them in such a way that the orifice o is put in communication with the pipe T, which brings in the water. The result of this is that as soon as the piston B is at the end of its stroke, the bottom of the piston G is in communication with the water; the pressures upon the pistons G and H therefore balance each other. But as the upper rod of the piston K is a little larger in diameter than its lower rod, the water raises the three pistons and replaces them in their original position. The top of the piston B is in communication with the escape-pipe E, and the pressure under the piston s raises this piston, and consequently the loaded piston B, as well as the pump-piston u. When the loaded piston has been raised to the position it occupies in the figure, a lower pin t has moved the lever l to bring down the pistons p and p', and make the engine begin again the downward stroke.

The pressure of the water is 116 mètres; the stroke of the pistons B and U is $1^{m}\cdot05$; the engine makes $2\frac{15}{100}$ strokes a minute; and the salt water is raised by the pump to a height of 378 mètres, including the suction; the stroke of the pistons K, H, G, is $0^{m}\cdot330$. The volume of water expended at each double stroke may be resolved thus;—

1. For the downward stroke there is expended a cylinderful for piston B;

$$\frac{\pi}{4} \times \overline{0\cdot720}^2 \times 1^{m}\cdot05 \quad \ldots \quad 428 \text{ litres.}$$

2. To change the direction of the motion, a cylinderful is expended for piston G;

$$\frac{\pi}{4} \times \overline{0\cdot235}^2 \times 0^{m}\cdot33 \quad \ldots \quad 10 \text{ litres.}$$

3. To raise the pistons S, T, U, a cylinderful is expended for piston S;

$$\frac{\pi}{4} \times \overline{0\cdot285}^2 \times 1^{m}\cdot05 \quad \ldots \quad 67 \text{ litres.}$$

4. To change the direction of the motion, that is, to determine the ascent of the three pistons S, T, U, there is expended only the difference between a cylinderful of G and a cylinderful of K;

$$\frac{\pi}{4}\left(\overline{0\cdot235}^2 - \overline{0\cdot195}^2\right) \times 0^{m}\cdot33 = 4\cdot15 \text{ litres, say 5 litres.}$$

The total expenditure of motive water (fresh water) is thus 510 litres, say 500 in round numbers.

Motive work in horse-power a second, $M\,w = \dfrac{500^{k} \times 116^{m} \times 2^{s}\cdot15}{60 \times 75^{kg}} = 28$ horse-power.

The pump U raises at each stroke 67 litres $\left(\frac{\pi}{4} \times \overline{0\cdot285}^2 \times 1^{m}\cdot05 = 67 \text{ litres}\right)$, weighing about $1\cdot20$ kilogramme the litre, to a height of 378 mètres. The effective work in horse-power a second is therefore $E\,w\ \dfrac{80^{k} \times 378^{m} \times 2^{s}\cdot15}{60'' \times 75^{kg}} = 14$ horse-power.

The work *in water raised* is therefore 50 per cent.

These calculations are only approximative, since they suppose that the volume generated by the pistons is just the volume expended or raised, and that there is no loss from escapes.

The engine erected by M. Jüncker at the Huelgoat Mines (Finistère), a vertical section of which is shown in Fig. 4156, is an imitation of Reichenbach's. It is, however, much more powerful and more rigid. The well in which it is fixed, offered only a limited space, and consequently its erection required special arrangements. The pump, too, which it had to work, being situate at a great depth beneath the engine, a long, heavy rod had to be balanced. This last circumstance induced M. Jüncker to make the engine work with an upward stroke only, in order that the rod might be subjected to tension in transmitting to the pump the work requisite to raise the water.

As the Huelgoat engine works only with an upward stroke the upper part of the cylinder is

open, and the leakage of the piston may therefore be readily perceived; this is not the case in Reichenbach's engine.

The adit is situate 14 mètres above the engines, so that the weight of all the tackle is balanced, for the ascent, by a column of water 14 mètres high, having as a base the section of the loaded piston. The introduction and discharge of the water, and consequently the speed of the engine, is regulated by means of the piston G. The figure shows this piston in its middle position; it closes the admission-port C beneath the loaded piston.

The engine is started by opening the cock R, which puts the inlet-pipe A in communication with the space between the two pistons p, p', which is of the same diameter; the cock c is also open. In order that the pistons p and p' may be easily brought into the position shown in the figure, that is, so as to uncover the orifice of the pipe o o, which puts the pipe a in communication with the top of the piston H, a pipe t is made to afford communication between the two fans of the piston p; the diameter of the rod i of this piston is such that the pressure of the water upon the annular surface of the piston p around the rod i is exactly equal to the counter-pressure beneath the piston p'. The moving hand of the pistons p and p' puts the two faces of the piston H in communication, and, as the annular surface of the upper face, increased by the section of the piston G, is a little greater than the area of the lower face, the water forces down the whole of the pistons K, H, and G, and opens the port C, through which the water is let under the piston B. The ball s at the end of the rod of the piston G enters a small cylinder v bored to a diameter only a very little greater than that of the ball; the water in this cylinder breaks the descent of the parts and prevents a shock. When the piston B is near the end of its stroke, a system of pins and levers raises the pistons p and p', so as to put the pipe o o in communication with the escape-pipe e e. This causes the piston G to ascend, which, passing before the port C, rises above, to put the lower face of the piston B in communication with the eduction-pipe E. The piston B then descends, and another system of pins brings back the pistons p and p' to the position shown in the figure, when the piston B has arrived at the end of its stroke.

We ought to remark here that the passage of the distributing piston in front of the port C has the effect of stopping for an instant the loaded piston B when it has reached the ends of its stroke. The dead-points of the pump are in this way very distinctly marked; this is a favourable circumstance, as it allows the valves time to close. This arrangement also causes the piston to start slowly in either direction, which gives the valves time to open fully before the pump-piston has acquired its full speed. The engine may be stopped at any part of its stroke, and the stroke may be varied as required. Thus Jüncker's engine is the most perfect of any at present employed.

Pfetsh's Horizontal, Double-action Engine, erected at the Salt-works of St. Nicholas, at Varangeville.—This engine, a section of which is shown in Fig. 4157, works directly a horizontal double-action pump, by means of the rod t. The engine being a double-action one, it has two distributing pistons g and h (the diameter of the second being a little greater than that of the first), which put successively each face of the piston B in communication with the induction-pipe A and the eduction-pipe E. The distributing pistons are worked as in Jüncker's engine, by means of two small pistons P and P' of equal diameter.

In the position shown in the figure, the pistons P and P' put the fore face of the piston K in communication with the escape e; the distributing pistons g and h (both on the same rod) are then placed in the position shown in the figure, so that the piston B is about to move in the direction of the arrow. On approaching the end of its stroke, the piston B acts upon the rod t and places the pistons P and P' so that the orifices o and a are comprised between them; the water then presses upon the fore face of the piston K: this causes g and h to move back so that the fore part of the cylinder is in communication with the pipe A, and the after part in communication with the orifice E of the escape-pipe. The piston B then begins its back stroke, and, having reached the end, it acts upon the rod t to bring back the pistons P and P' to the positions they occupy in the figure; this causes g and h to replace each other, as the figure also shows.

Reciprocating engines have been used during the last few years to turn a shaft. Since the Exhibition of 1851 they have become common in England, especially among the lead mines of the North, where they are used to raise the ore. Sir Wm. Armstrong is the chief constructor of this kind of double-action engine, which he employs to work whims. They consist, in their essential parts, of two horizontal cylinders, the pistons of which drive two cranks at right angles. A distributing apparatus comprising, for each cylinder, a *normal* slide-valve, that is, without lead or overlap, which must be regulated with great nicety on account of the incompressibility of the water. These engines have between the diameter and the stroke of the pistons the usual proportions of a water-pump, and they work at a low rate of speed, generally less than twenty revolutions a minute. The induction-pipe should be provided with the necessary means for avoiding ram strokes, namely, an air-vessel, or safety-valves, or a plunger loaded with weights and moving in a pump-barrel fixed near the engine and in communication with the induction-pipe. The motion of the slide-valves is communicated by means of link-motion, which enables the engine to be reversed, so as to drive the whim sometimes in one direction and sometimes in the other. If the reversing is not required, the distribution may be effected by a three-way cock R, Fig. 4158. In the position shown in the figure, the port l is in communication with the inlet a; whilst the port l is in communication with the escape e, the piston B is moving in the direction of the arrow.

It is indispensable that the water employed in these engines should be quite free from gravel and other bodies in suspension, which would soon injure the rubbing parts.

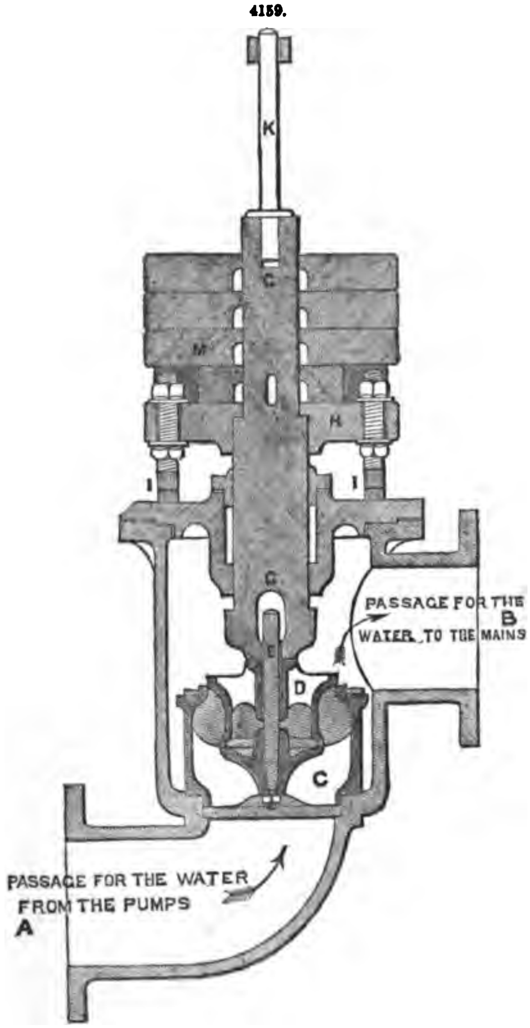
Sir Wm. Armstrong has also constructed triple engines, with double-action, the three pistons of which drive three cranks conjugated at 120°. As an example, we will cite the 8 horse-power engine at the docks of Marseilles. It has three horizontal oscillating cylinders, and it drives a cranked shaft. The hollow axis of each oscillating cylinder receives the water on one side, and on the other works its slide-valve, which is wholly detached from the cylinder. These cylinders are $0^{m}\cdot107$ in diameter from inside to inside, and the stroke of the pistons is $0^{m}\cdot304$. As the engine

makes twenty revolutions a minute, it follows that the mean velocity of the pistons is only $\frac{0^m \cdot 304 \times 2 \times 20^r}{60''} = 0^m \cdot 203$ a second.

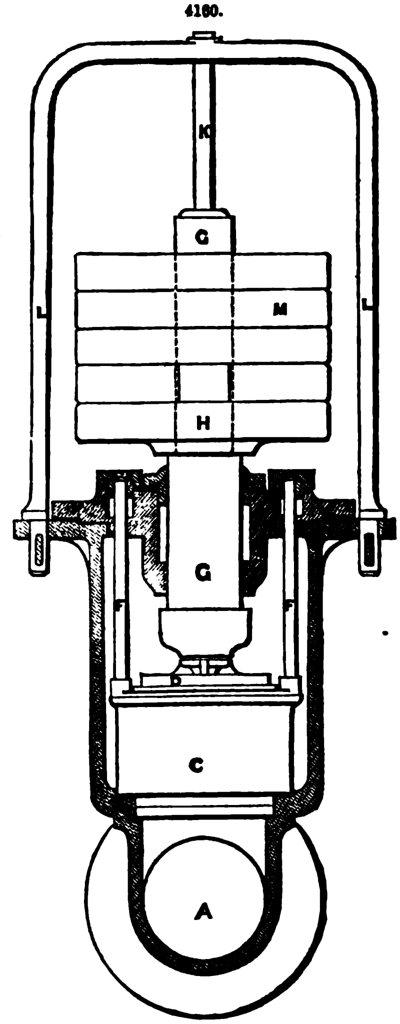
Substitute for a Stand-pipe, invented by Samuel Hocking, C.E., who first applied it to the Croydon Water-works in 1851.—In applying the single-acting Cornish engine to water-works where there is a variable pressure in the mains, a stand-pipe was added to maintain a uniform resistance against the action of the engine.

When the Croydon Water-works was designed by Mr. Ranger in 1850, it was considered that the storage reservoir on the hill was near enough to the engines to serve for the ordinary stand-pipe; and the engines were contracted for accordingly, that is to say, to work without the usual stand-pipe. Subsequently, however, the contractor's engineer, Samuel Hocking, who designed and erected these engines, finding that the town was to be supplied by branch pipes leading off from the main that conveyed the water from the engines to the reservoir, and that any breakage taking place in those branches might so lessen the resistance against the pumps as to endanger the safety of the engines, the entire risk of which was guaranteed by the contractors for one year, he contrived a cheap substitute for the ordinary stand-pipe, which the contractors supplied at their

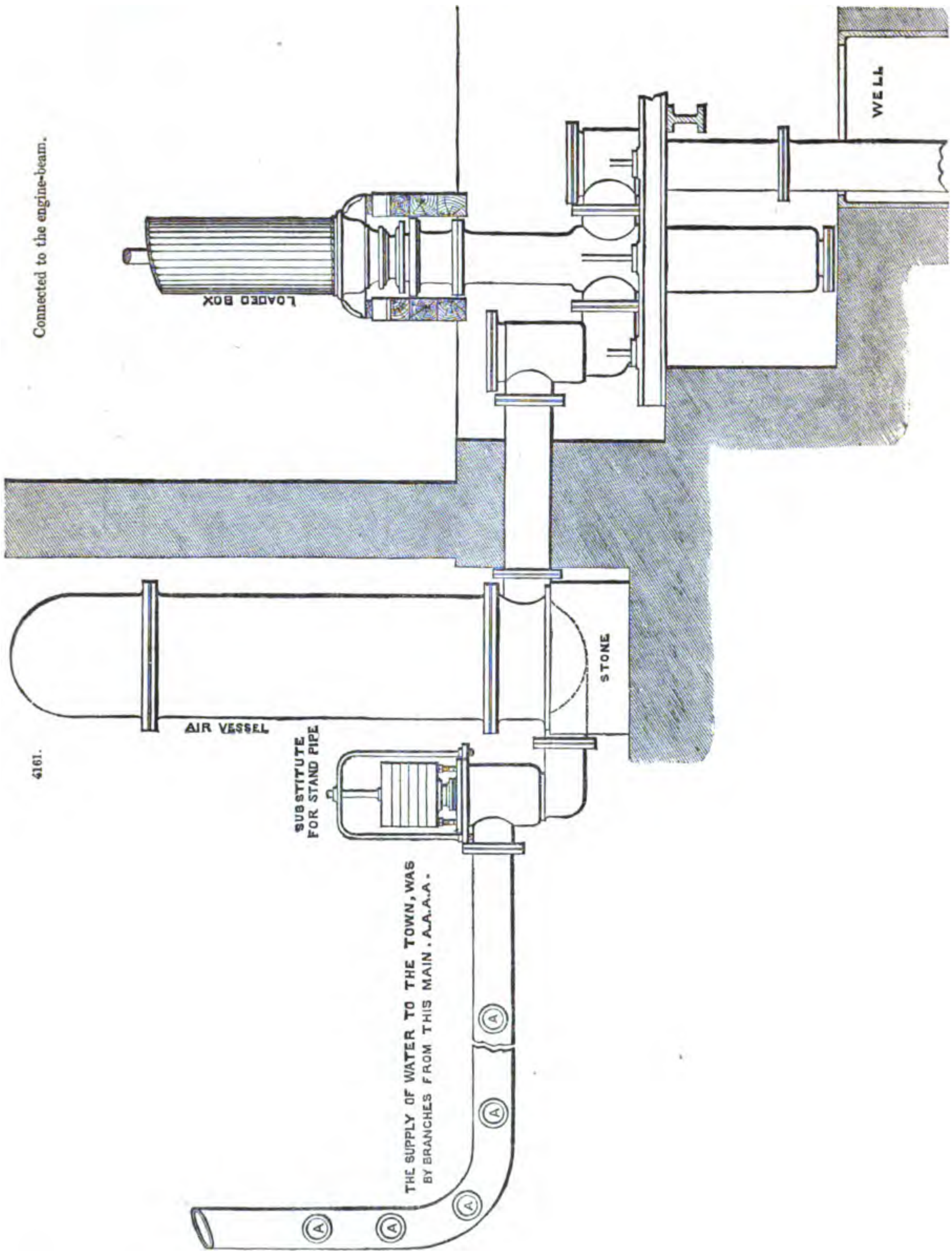
4159.



4160.



A, Branch joining air-vessel. B, Branch joining the main. C, Valve-seat. D, Valve, with small opposing surface to the flow of water through it. E, Valve-spill, fixed to the seat; and to get ample room for the top end of it, there is a hole in the bottom end of the plunger. N.B.—The valve here is free, but it may be hung fast to the plunger. F F, Bolts for fixing the valve-seat. G, Plunger, with a collar to limit its lift. H, Lowermost weight, fixed to the plunger. I I, Legs, to prevent the falling plunger striking hard on the valve. K, Lengthening-piece on top end of plunger. L, Guide for ditto.

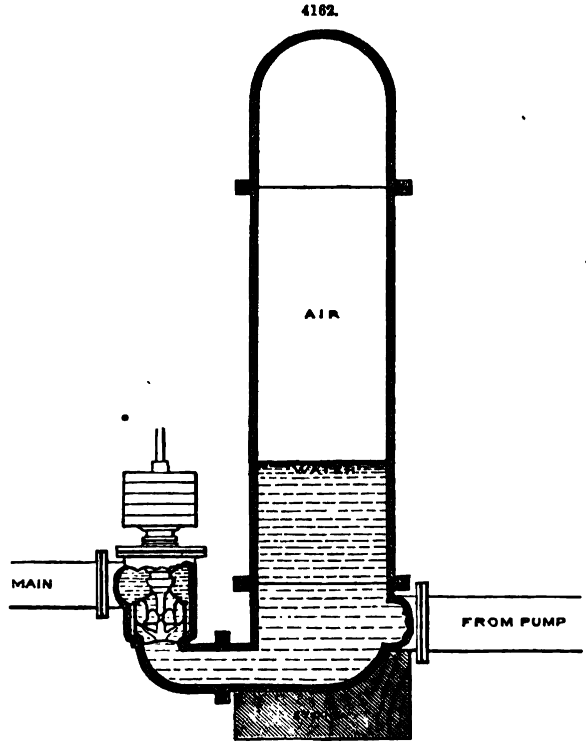

Connected to the engine-beam.
LOADED BOX
WELL
STONE
AIR VESSEL
SUBSTITUTE FOR STAND PIPE
THE SUPPLY OF WATER TO THE TOWN, WAS BY BRANCHES FROM THIS MAIN. A.A.A.A.
A
A
A
A
A
A

4161.

own cost rather than incur the risk of accident to the engines from that source during their period of guarantee.

This ingenious substitute for a stand-pipe, the construction and application of which we illustrate, Figs. 4159 to 4162, has a valve that is made to shut against the flow of water issuing from the pumps, which valve must open before any water can get into the main. It also has a plunger, or *hydraulic ram*, passing through a stuffing box over the valve; the bottom end of the plunger rests on the valve inside, and the top end of it carries a weight outside the main. The outside end of the plunger is loaded with weights amounting to a little less than that due to the full hydraulic pressure acting against the inside end of it. When the mains are under full pressure, this plunger is lifted up to its limit of travel, and the valve left free to act, nothing bearing on the valve but the pressure due to the column of water confined in the main. Whenever the hydraulic pressure in the mains gets reduced through accident or otherwise, the excess of weight on the plunger will bring it down to bear on the top of the valve, where it will act with that portion of its weight that is not balanced by the diminished hydraulic pressure in the main, thus maintaining a uniform load on the valve, and a uniform resistance against the engines. In starting, the engines have to pump against a weighted valve instead of a given column of water; and when the column is full, the weights cease to act.

4162.



Section of air-vessel, Fig. 4161.

Had a common flat valve been used, the plunger above it would then be of the same diameter, requiring an unwieldy weight; but by reducing the area of the valve exposed to the upward flow of water, after the manner of construction of the ordinary double-beat valve, a small size plunger with manageable weights suffices.

To explain the construction of this apparatus more particularly, reference being made to Figs. 4159, 4160;—

A, that part of the apparatus that is fixed to the engine-pump, and through which all the water pumped has to pass to the valve C D, and thence to the mains through B.

C D, valve-seat and valve of the double-beat kind, the valve D working on a central spindle E.

F F, two bolts for screwing down the valve-seat from outside.

G, plunger-pole or ram, with a collar to prevent its rising too high; and a recess cast in the bottom end of it to give ample length of guide-spill for the valve.

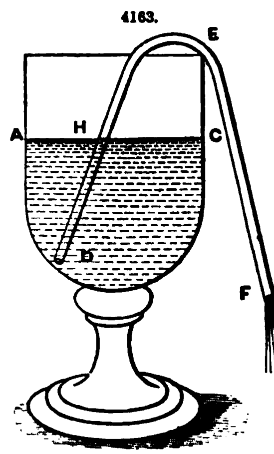
H, a heavy cast-iron block, forming a round table for carrying the weight used for loading the plunger; it is securely fixed to the plunger-pole. It has two adjusting studds as legs, marked I I, on which the weight of the loaded plunger acts, thereby preventing it from striking on the valve, in case of sudden removal of hydraulic pressure by breakage of the mains.

K, wrought-iron lengthening-piece to the cast-iron plunger, over which the cast-iron weights M M slide off and on to adjust the load on the plunger when required.

L, a wrought-iron guide to steady the top end of the plunger-pole.

The beats of the valve C D are made very narrow—less than ⅛ of an inch—to prevent the heavy jumping action that would have been occasioned by wide beats; before the valve opens, the force is measured by the surface within the beats, but the instant the valve moves, it is measured by the outside diameters.

4163.



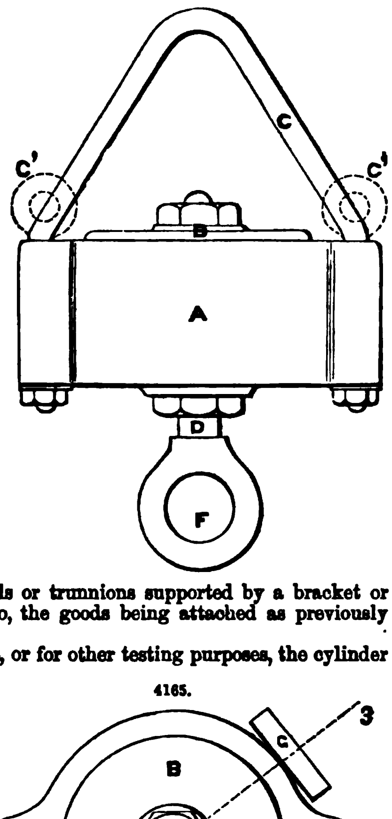
The Siphon.—If one end of a bent tube be put into a vessel of water, Fig. 4163, and the other end without be lower than the

surface of the water, then if the air be extracted out of the tube D E F, or the tube be filled with water, the water will flow through the tube in a continued stream, until the surface of the water in the vessel is on a level with the extremity F. For when the air is drawn out of the siphon, the water will rise in it to E by the pressure of the atmosphere upon the surface of the water A C, and then it will descend to F by its own gravity. The siphon being full of water, the forces which act upon the water in the tube are the pressure of the atmosphere upon the surface A C, and the weight of the column of water E F, acting in the direction D E F; and the pressure of the air at F, and the weight of the column of water E H, acting in the opposite direction F E D. The pressure of the air on F and an equal surface of A C, may be considered equal to each other, for the difference of the altitudes of A C and F is too small to produce any appreciable effect on the pressure of the air; these pressures on the tube D E F will therefore balance each other. But the weight of the column of water E F being greater than the weight of the column of water E H, the sum of the pressures in the direction D E F is greater than the sum of the pressures in the direction F E D; the fluid, therefore, will continue to flow in the direction D E F until the surface of the fluid A C is on a level with F.

The siphon will not act if the height H E be greater than 33 ft., for then the pressure of the atmosphere on the surface A H will not be sufficient to raise the water to the highest point E.

Hydraulic Weighing Machine.—This machine, Figs. 4164 to 4166, invented by F. E. Duckham, presents improved appliances and furnishes a means of attachment for the goods to be weighed, whereby they may be suspended from the piston instead of being placed directly upon it; in this manner all liability to press unequally on the piston is avoided, as well as the consequent development of undue friction between the piston and the sides of the cylinder, which frequently occurs when goods are placed on a platform formed by the top surface of the piston. For this purpose the inventor suspends or attaches the apparatus or cylinder by means of a suitable stirrup-piece or sling connected to a link from a crane or in other convenient position. The goods to be weighed are suspended from the centre of the piston by means of a piston-rod which passes through a suitable water-tight gland or packing in the bottom of the cylinder, and to the lower end of which rod the goods to be weighed are attached. A pressure-gauge communicates as usual with the liquid in the cylinder for the purpose of indicating the degree of pressure on such liquid, or in other words the weight of the goods suspended.

4164.



Instead of employing a central piston-rod passing through the bottom of the cylinder, the goods may be suspended by means of an inverted stirrup-piece, similar to that by which the apparatus is sustained, and which is passed over the top of the piston and down through guides placed on the outside of the cylinder, below which it is united in a link, to which the goods may be attached. In this case the top of the piston should be made of sufficient diameter to project slightly over the top of the cylinder.

Instead of suspending the apparatus by means of a sling or stirrup-piece, it may be mounted in gimbals or trunnions supported by a bracket or shelf, or the apparatus may be bolted securely thereto, the goods being attached as previously described.

When this contrivance is employed to denote strains, or for other testing purposes, the cylinder is firmly secured in a vertical or other position, and tension applied to the piston-rod or stirrup-piece, the strain being denoted on the pressure-gauge as before.

4165.

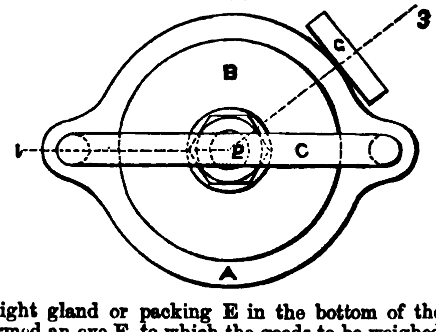
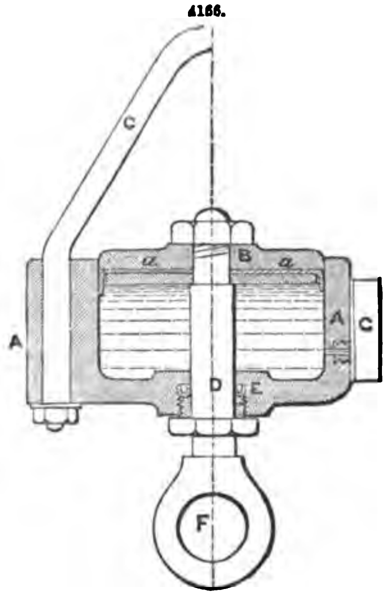


Fig. 4164 is an outside elevation of one arrangement of this hydrostatic weighing apparatus; Fig. 4165 a plan, and Fig. 4166 a sectional elevation taken on line 1, 2, 3, Fig. 4165. A is the cylinder containing water or other suitable liquid, on the surface of which rests a piston or plunger B. To this cylinder A is bolted a stirrup-piece C, by which we may suspend the apparatus from a crane or apply it in any other convenient position. Instead of a stirrup-piece the apparatus may be slung by a chain or chains attached to eye-bolts C^1 C^1, connected to the cylinder. D is the piston-rod passing down through a water-tight gland or packing E in the bottom of the cylinder A. At the lower end of this rod D is formed an eye F, to which the goods to be weighed are attached. The latter are thus suspended from the centre of piston B, on which the pressure will be uniformly distributed. G is a pressure-gauge of any suitable construction, and communicating with the liquid in the cylinder, for the purpose of indicating the weight of the goods suspended from piston-rod D, the connection being either through the back of the gauge, as

shown in Fig. 4166, or through the rim of the gauge, or the connection may be at any other convenient point. The piston B and gland E are made water-tight either by means of cup-leathers of the usual form, as shown at *a a*, in Fig. 4166; many other arrangements may be employed to render the piston water-tight.

4166.



This weighing machine, like many hydraulic contrivances, is only a particular application of the principle upon which Timothy Bramah constructed his famous press, of which we treat next.

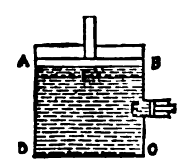
The Hydrostatic or Bramah Press.—The following article on Bramah's Press is taken from Alexander Jamieson's excellent work, Mechanics of Fluids for Practical Men;—

If there be any number of pistons of different magnitudes, anyhow applied to apertures in a cylindrical vessel filled with an incompressible and non-elastic fluid,

The forces acting on the piston to maintain an equilibrium, will be to one another as the areas of the respective apertures, or the squares of the diameters of the pistons.

Let A B C D, Fig. 4167, represent a section passing along the axis of a cylindrical vessel filled with an incompressible and non-elastic fluid, and let E F be two pistons of different magnitudes, connected with the cylinder and closely fitted to their respective apertures or orifices; the piston F being applied to the aperture in the side of the vessel, and the piston E occupying an entire section of the cylinder or vessel, by which the fluid is contained. Then, because by the nature of fluidity the pressures on every part of the pistons E and F are mutually transmitted to each other through the medium of the intervening fluid, it follows that these pressures will be in a state of equilibrium when they are equal among themselves.

4167.



Now it is manifest that the sum of the pressures propagated by the piston E is proportional to the area of a transverse section of the cylinder; and in like manner the sum of the pressures propagated by the piston F is proportional to the area of the aperture which it occupies; consequently an equilibrium must obtain between these pressures,

When the forces on the pistons are to one another respectively as the areas of the apertures or spaces which they occupy.

And it is obvious that the same thing will take place, whatever may be the number of the pistons pressed.

Hence it appears that by taking the areas of the pistons E and F in a proper ratio to one another, we can, by means of an incompressible fluid, produce an enormous compression, and that too by the application of a very small force.

Put P = the force or pressure on the piston E,
A = the area of the orifice which it occupies,
p = the pressure on the piston F, and
a = the area of the orifice or space to which it is fitted.

Then, according to the principle announced in the foregoing proposition and demonstrated above, we shall obtain $a : A :: p : P$.

But because, by the principles of mensuration, the areas of different circles are to one another as the squares of their diameters; if therefore we substitute d^2 and D^2 respectively for a and A in the above analogy, we shall have $d^2 : D^2 :: p : P$, and from this, by making the product of the mean terms equal to the product of the extremes, we get

$$p\,D^2 = P\,d^2. \qquad [A]$$

This is the principle upon which depends the construction and use of that very powerful instrument, the *Hydrostatic Press*, first brought into notice about the year 1796, by Joseph Bramah, of London, who announced it to the world as the discovery of a new mechanical power. In this, however, he was mistaken, for although the principle upon which it depends may be said to constitute a seventh mechanical power, yet the principle was not new to philosophers at the time when Bramah applied it to the construction of his presses, it having long been familiarly known under the designation of the *Hydrostatic Paradox;* and besides, the celebrated Pascal obscurely hinted at its application to mechanical purposes, but did not pursue the idea far enough to produce anything useful, or to entitle him to the merit of the discovery.

The improvement introduced by Bramah consisted in the application of the common forcing pump to the injection of water, or some other incompressible and non-elastic fluid, into a strong metallic cylinder, truly bored and furnished with a movable piston, made perfectly water-tight by means of leather collars or packing, neatly fitted into the cylinder.

The proportion which subsists between the diameter of this piston and that of the plunger in the forcing pump, constitutes the principal element by which the power of the instrument is

calculated; for, by reason of the equal distribution of pressure in the fluid, it is evident that whatever force is applied, that force must operate alike on the piston in the cylinder, and on the plunger in the forcing pump, and consequently,

In proportion as the area of the transverse section of the one exceeds the area of a similar section of the other, so must the pressure sustained by the one exceed that sustained by the other.

Therefore if the piston F in the preceding diagram be assimilated to the plunger in the barrel of a forcing pump, and the piston E to that in the cylinder of the hydrostatic press; then the equation marked [A], notwithstanding the very simple and concise form in which it appears, involves every particular respecting the power and effects of the engine.

This being premised, we shall now proceed to exhibit the use and application of the formula, by the resolution of the following practical examples.

Ex. 1.—If the diameter of the cylinder is 5 in., and that of the forcing pump 1 in.; what is the pressure on the piston in the cylinder, supposing the force applied on the plunger or smaller piston to be equivalent to 750 lbs.?

Here we have given $D = 5$ in.; $d = 1$ in., and $p = 750$ lbs.; therefore, by substitution, equation [A] becomes $5^2 \times 750 = P \times 1^2$; that is, $P = 18750$ lbs.

Or the equation for the value of P may be expressed in general terms as follows; $P = \frac{p\,D^2}{d^2}$.

And from the equation in its present form we deduce the following practical rule.

Rule.—*Multiply the square of the diameter of the cylinder by the magnitude of the power applied, and divide the product by the square of the diameter of the forcing pump, and the quotient will express the intensity of the pressure on the piston of the cylinder.*

Ex. 2.—If the diameter of the cylinder is 5 in., and that of the forcing pump 1 in.; what is the magnitude of the power applied, supposing the entire pressure on the piston of the cylinder to be 18750 lbs.?

Here we have given $D = 5$ in.; $d = 1$ in., and $P = 18750$ lbs.; therefore, by substitution, equation [A] becomes $5^2 \times p = 18750 \times 1^2$; or $p = 750$ lbs.

If both sides of the fundamental equation [A] be divided by D^2, the general expression for the value of p is $p = \frac{P\,d^2}{D^2}$.

And the practical rule which this equation supplies may be expressed in words at length in the following manner.

Rule.—*Multiply the given pressure on the piston of the cylinder by the square of the diameter of the forcing pump, and divide the product by the square of the diameter of the cylinder for the power required.*

Ex. 3.—The diameter of the forcing pump is 1 in., and the power with which the plunger descends is equivalent to 750 lbs.; what must be the diameter of the cylinder, to admit a pressure of 18750 lbs. on the piston?

Here we have given $d = 1$ in.; $p = 750$ lbs., and $P = 18750$ lbs.; consequently, by substitution, the equation marked [A] becomes $750\ D^2 = 18750 \times 1^2$; hence, by division, we obtain $D^2 = \frac{18750}{750} = 25$; consequently, by evolution, we have $D = \sqrt{25} = 5$ in.

If both sides of the equation [A] be divided by p, and the square root of the quotient extracted, the general expression for the diameter of the piston is $D = \sqrt{\frac{P\,d^2}{p}}$.

And the practical rule for the determination of D may be expressed in words as follows.

Rule.—*Multiply the pressure on the piston of the cylinder by the square of the diameter of the forcing pump, and divide the product by the force with which the plunger descends; then the square root of the quotient will be the diameter of the cylinder sought.*

Ex. 4.—The diameter of the cylinder is 5 in., and the force with which the plunger descends is equivalent to 750 lbs.; what must be the diameter of the forcing pump, in order to transmit a pressure of 18750 lbs. to the piston of the cylinder?

Here we have given $D = 5$ in.; $p = 750$ lbs., and $P = 18750$ lbs.; consequently, by substitution, equation [A] becomes $18750\,d^2 = 750 \times 5^2$, and by division we shall have $d^2 = \frac{750 \times 25}{18750} = 1$; therefore, by extracting the square root, we get $d = \sqrt{1} = 1$ in.

If both sides of the original equation marked [A] be divided by P, and the square root extracted, the entire pressure on the piston, the general expression for the value of d becomes $d = \sqrt{\frac{p\,D^2}{P}}$

And the practical rule which this equation supplies may be expressed in the following manner.

Rule.—*Multiply the force with which the plunger descends by the square of the diameter of the cylinder, and divide the product by the entire pressure on the piston; then extract the square root of the quotient for the diameter of the forcing pump.*

The foregoing is the theory of the hydrostatic press, as restricted to the consideration of the diameters of the cylinder and forcing pump, and the respective pressures on the piston and plunger; but since the instrument is generally furnished with an *indicator* or *safety-valve* for measuring the intensity of pressure, the theory would be incomplete without considering it in connection with the diameters of the pump and cylinder. For which purpose

Put δ = the diameter of the safety-valve, expressed in inches or parts,
and w = the weight thereon, or the force that prevents its rising.

Then, according to the principle announced, p. 1983, we obtain the following analogies, namely;—

$$D^2 : \delta^2 :: P : w,$$
$$d^2 : \delta^2 :: p : w;$$

and from these analogies, by making the products of the extreme terms equal to the products of the means, we get

$$D^2 w = \delta^2 P, \qquad [B]$$
$$\text{and} \quad d^2 w = \delta^2 p. \qquad [C]$$

Now, in order to pursue the expansion of these equations, we shall suppose the value of δ to be one-fourth of an inch, while the numerical values of the other letters remain the same as supposed for the several examples under equation [A]; then, to determine the corresponding value of w, or the power which prevents the safety-valve from rising, when all the parts of the instrument, or the several powers and pressures, are in a state of equilibrium, we have the following examples to resolve according to the proposed conditions.

Ex. 5.—The diameter of the cylinder is 5 in., that of the indicator or safety-valve $\frac{1}{4}$ of an inch, and the entire pressure upon the piston of the cylinder 18750 lbs.; what is the corresponding force preventing the ascent of the safety-valve, on the supposition of a perfect equilibrium?

Here we have given $D = 5$ in.; $\delta = \frac{1}{4}$ of an inch, and $P = 18750$ lbs.; consequently, by substitution, the equation [B] becomes $5^2 w = \cdot 25^2 \times 18750$; from which, by division, we get

$$w = \frac{\cdot 0625 \times 18750}{25} = 46 \cdot 875 \text{ lbs.}$$

But the general expression for the value of w, as derived from the equation [B], becomes $w = \frac{\delta^2 P}{D^2}$, from which we derive the following rule.

RULE.—*Multiply the entire pressure on the piston of the cylinder by the square of the diameter of the indicator or safety-valve, and divide the product by the square of the diameter of the cylinder for the weight required.*

Ex. 6.—The diameter of the safety-valve is $\frac{1}{4}$ of an inch, that of the cylinder 5 in., and the weight on the safety-valve 46·875 lbs., what is the corresponding pressure on the piston of the cylinder?

Here we have given $\delta = \frac{1}{4}$ of an inch; $D = 5$ in., and $w = 46 \cdot 875$ lbs.; therefore, by substitution, equation [B] becomes $\cdot 25^2 P = 5^2 \times 46 \cdot 875$, and by division we obtain

$$P = \frac{1171 \cdot 875}{\cdot 0625} = 18750 \text{ lbs.}$$

The general expression for the value of P, as derived from the equation marked [B], becomes

$$P = \frac{D^2 w}{\delta^2}.$$

And the practical rule supplied by this equation may be expressed in words as follows.

RULE.—*Multiply the weight on the safety-valve by the square of the diameter of the cylinder, and divide the product by the square of the diameter of the safety-valve, and the quotient will give the entire pressure on the piston of the cylinder.*

Ex. 7.—The diameter of the cylinder is 5 in., the entire pressure of the piston is 18750 lbs., and the weight on the safety-valve is 46·875 lbs.; what is its diameter?

Here we have given $D = 5$ in.; $P = 18750$ lbs., and $w = 46 \cdot 875$ lbs.; therefore, by substitution, equation [B] becomes $18750\,\delta^2 = 5^2 \times 46 \cdot 875$, and from this, by division, we get $\delta^2 = \frac{5^2 \times 46 \cdot 875}{18750} = \cdot 0625$; and by extracting the square root, we obtain $\delta = \sqrt{\cdot 0625} = \cdot 25$, or $\frac{1}{4}$ of an inch.

The general expression for the value of δ, as derived from the equation [B], is as follows, namely, $\delta = \sqrt{\frac{D^2 w}{P}}$.

And the practical rule which this equation affords may be expressed in words in the following manner.

RULE.—*Multiply the load on the safety-valve by the square of the diameter of the cylinder, divide the product by the entire pressure on the piston, and the square root of the quotient will give the diameter of the safety-valve required.*

Ex. 8.—The diameter of the safety-valve is $\frac{1}{4}$ of an inch, the load upon it 46·875 lbs., and the entire pressure on the piston of the cylinder is 18750 lbs.; what is its diameter?

Here we have given $\delta = \frac{1}{4}$ of an inch, $w = 46 \cdot 875$ lbs., and $P = 18750$ lbs.; consequently, by substitution, we have $46 \cdot 875\,D^2 = \cdot 25^2 \times 18750$, from which, by division, we shall obtain $D^2 = \frac{\cdot 25^2 \times 18750}{46 \cdot 875} = 25$, and finally, by extracting the square root, we get $D = \sqrt{25} = 5$ in.

If both sides of the equation marked [B] be divided by w, the weight on the safety-valve, we get $D^2 = \frac{\delta^2 P}{w}$, and by extracting the square root, the general expression for the value of D, the diameter of the cylinder, becomes $D = \sqrt{\frac{\delta^2 P}{}}$. And from this equation we derive the following rule.

RULE.—*Multiply the entire pressure on the piston of the cylinder by the square of the diameter of the safety-valve, divide the product by the weight upon the safety-valve, and extract the square root of the quotient for the diameter of the cylinder sought.*

Ex. 9.—The diameter of the forcing pump is 1 in., that of the safety-valve is ¼ of an inch, and the power or force with which the plunger descends is equivalent to 750 lbs.; what is the corresponding weight on the safety-valve?

Here we have given $d = 1$ in.; $\delta = \frac{1}{4}$ of an inch, and $p = 750$ lbs.; consequently, by substitution, the equation [C] becomes $1^2 \times w = \cdot 25^2 \times 750$; that is, $w = 46 \cdot 875$ lbs., the very same value as we derived from the fifth example.

If both sides of the equation marked [C] be divided by d^2, the general expression for the value of w becomes $w = \frac{\delta^2 p}{d^2}$.

And the practical rule supplied by this equation may be expressed in words at length in the following manner.

RULE.—*Multiply the force with which the plunger descends by the square of the diameter of the safety-valve, and divide the product by the square of the diameter of the plunger; then the quotient will express the load upon the safety-valve.*

Ex. 10.—The diameter of the safety-valve is ¼ of an inch, that of the forcing pump is 1 in., and the load upon the safety-valve is 46·875 lbs.; what is the power applied, or the force with which the plunger in the forcing pump descends?

Here we have given $\delta = \frac{1}{4}$ of an inch, $d = 1$ in., and $w = 46 \cdot 875$ lbs.; consequently, by substitution, equation [C] becomes $\cdot 25^2 p = 46 \cdot 875 \times 1^2$, and from this, by division, we obtain

$$p = \frac{46 \cdot 875}{\cdot 0625} = 750 \text{ lbs.}$$

The general expression for the value of p, as obtained from the equation marked [C], becomes $p = \frac{d^2 w}{\delta^2}$, from which we derive the following rule.

RULE.—*Multiply the load on the safety-valve by the square of the diameter of the forcing pump, then divide the product by the square of the diameter of the safety-valve, and the quotient will give the force with which the piston descends.*

Ex. 11.—The diameter of the plunger or the piston of the forcing pump is 1 in., the force with which it descends is equivalent to 750 lbs., and the load on the safety-valve is 46·875 lbs.; what is its diameter?

Here we have given $d = 1$ in., $p = 750$ lbs., and $w = 46 \cdot 875$ lbs.; consequently, by substitution, we have $750\ \delta^2 = 1^2 \times 46 \cdot 875$, and from this, by division, we obtain $\delta^2 = \frac{46 \cdot 875}{750} = \cdot 0625$, and finally, by evolution, we have $= \delta \sqrt{\cdot 0625} = \cdot 25$ of an inch.

Let both sides of the equation marked [C] be divided by p, the power or force with which the piston of the forcing pump descends, and we shall have $\delta^2 = \frac{d^2 w}{p}$, and by extracting the square root we get $\delta = \sqrt{\frac{d^2 w}{p}}$. Hence the following practical rule.

RULE.—*Multiply the weight or load upon the safety-valve by the square of the diameter of the forcing pump, and divide the product by the force with which the plunger or piston of the forcing pump descends; then the square root of the quotient will be the diameter of the safety-valve.*

Ex. 12.—The diameter of the safety-valve is ¼ of an inch, the weight upon it is 46·875 lbs., and the power applied, or the force with which the plunger descends, is 750 lbs.; what is the diameter of the forcing pump?

Here we have given $\delta = \frac{1}{4}$ of an inch, $w = 46 \cdot 875$ lbs., and $p = 750$ lbs.; consequently, by substitution, the equation marked [C] becomes $46 \cdot 875\ d^2 = \cdot 25 \times 750$; therefore, by division, we obtain $d^2 = \frac{\cdot 25^2 \times 750}{46 \cdot 875} = 1$, and finally, by extracting the square root, we get $d = 1$ in.

The general expression for the value of the diameter of the forcing pump, as derived from the equation [C], is $d = \sqrt{\frac{\delta^2 p}{w}}$. And from this we obtain the following practical rule.

RULE.—*Multiply the force with which the piston of the forcing pump descends by the square of the diameter of the safety-valve, divide the product by the load on the safety-valve, and extract the square root of the quotient for the diameter of the forcing pump.*

The foregoing twelve examples exhibit all the varieties of cases that can arise from the combination of the six data which we have employed in our theory, namely, the diameters of the cylinder, the forcing pump, and the safety-valve; together with the entire pressure on the piston of the cylinder, the power applied to the plunger of the forcing pump, and the weight upon the safety-valve.

We have determined each of the quantities composing the several fundamental equations in terms of the others, and have drawn up rules from the general expressions, merely for the assistance of those who are not accustomed to algebraic reductions; those who are will prefer finding each quantity directly from the general equation expressing its value.

It is manifest from the principles of mensuration that the area of a transverse section of the cylinder, or the base of the piston, is expressed by $\cdot 7854\ D^2$; and we have shown that the entire pressure upon the base of the piston in the case of equilibrium is $P = \frac{p D^2}{d^2}$, and $P = \frac{D^2 w}{\delta^2}$; conse-

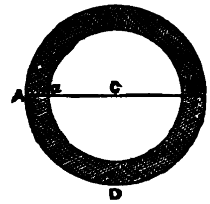
quently, if n denotes the pressure in pounds avoirdupois on one square inch of the piston, then we have

$$n = \frac{P}{\cdot 7854\,D^2};\ p = \frac{p}{\cdot 7854\,d^2},\ \text{and}\ n = \frac{w}{\cdot 7854\,\delta^2}. \qquad \text{[D]}$$

Now, from principles investigated by Peter Barlow, it appears that if c denote the cohesive force of the material employed in the construction of the cylinder, t its thickness, and r the interior radius, then, in order that the strain produced by the pressure shall not exceed the elastic power of the material, it is necessary that $n = \frac{c\,t}{t + r}$.

In order to demonstrate this, let A B D, Fig. 4168, be a transverse section of the cylinder, perpendicular to the axis passing through C; then, supposing a certain uniform pressure to be exerted all round the interior boundary, it will readily appear, from the theory of resistance, that each successive circular lamina, estimated from the interior towards the exterior circumference, offers a less and less resistance to the straining force.

4168.



But it is obvious from the very nature of the subject that by reason of the internal pressure or strain the metal must undergo a certain degree of extension; and since the resistance of the outer boundary is less than that of the inner one, it follows that the extension must also be less. This is manifest, for the resistance which any body offers to the force by which it is strained is proportional to the extension which it undergoes divided by its length. Now, since the resistances of the several laminæ decrease as they recede from the interior boundary towards the exterior, while at the same time the corresponding circumferences increase, it is manifest that the extension for the several laminæ decreases to the last or exterior boundary, where it is the least of all. It is therefore the law of the decreasing resistance that the present inquiry is instituted to determine.

Put $d = a\,b$, the interior diameter of the cylinder before the pressure is applied,
e = the increase of d occasioned by the pressure,
d' = A B, the exterior diameter in its original state,
e' = the increase induced by pressure.

Then $(d + e)$ and $(d' + e')$ are respectively the interior and exterior diameters of the cylinder as affected by extension.

By the principles of mensuration, the area of the annulus, or circular ring contained between the interior and exterior boundaries,

Is equal to the difference of the squares of the diameters, drawn into the constant fraction 0·7854; *or it is proportional to the sum of the diameters, drawn into their difference.*

But according to the nature of the present inquiry, the area of the ring is the same, both before and after the extension takes place; consequently we have $(d' + e')^2 - (d + e)^2 = d'^2 - d^2$; therefore, by expanding the terms on the left-hand side, we get $d'^2 + 2\,d'\,e' + e'^2 - d^2 - 2\,d\,e - e^2 = d'^2 - d^2$; or, by transposing and expunging the common terms, it is $2\,d'\,e' + e'^2 = 2\,d\,e + e^2$; and this equation being converted into an analogy, gives $2\,d' + e' : 2\,d + e :: e : e'$.

Now, the quantity of extension that the material will allow before rupture being very small, especially as compared with the quantities $2\,d'$ and $2\,d$, it therefore follows that the quantities e' and e, in the first and second terms, may be conceived to vanish, and the above analogy becomes $d' : d :: e : e'$.

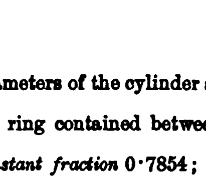
From this it appears that the extensions of the respective circumferences are inversely as the corresponding diameters; but we have stated above that the resistance is as the extension divided by the length; therefore we have $\frac{d}{d'} : \frac{d'}{d}$, or, which amounts to the same thing, $d^2 : d'^2$; hence this law, that the magnitude of the resistance offered by each successive circular lamina,

Is inversely as the square of its diameter, or, which is the same thing, inversely as the square of its distance from the common centre to which they are referred.

From the general law thus established, the actual resistance due to any point in the annulus, or to any thickness of metal, can very easily be ascertained.

Put r = C a, the interior radius of the cylinder, of which the annexed diagram, Fig. 4169, is a section,
t = a A, the entire thickness of the metal,
x = $a\,n$, any variable thickness estimated from a, the interior surface,
n = the pressure on a square inch of the inner surface in pounds avoirdupois,
f = the measure of the straining force, or the resistance sustained by the first or interior lamina; and
c = the cohesive force of the material.

4169.



Then, agreeably to the law of the resistances which we have established above, we have $(r + x)^2 : r^2 :: f : \frac{f\,r^2}{(r + x)^2}$; this result expresses the strain at the point x, or the resistance of the material whose thickness is $a\,n$; and the fluxion

of this quantity, as referred to the variable thickness x, is flux. $= \frac{f r^2 \dot{x}}{(r + x)^2}$; consequently the fluent, or the sum of all the strains, is $\int \frac{f r^2 \dot{x}}{(r + x)^2} + C$, and this when $x = t$ becomes

$$f\left(r - \frac{r^2}{r + t}\right) = \frac{f r t}{r + t}.$$

Therefore if the strain or resistance f were to act uniformly on the thickness expressed by $\frac{f r t}{r + t}$, it would produce the same effect as if all the variable strains were to act on the whole thickness t.

The above law being admitted, let us suppose that the interior radius of the cylinder, and the pressure a square inch on the surface are given, and let it be required to determine the thickness such that the strain and resistance may be in equilibrio.

Here it is manifest that the greatest strain the thickness $\frac{r t}{r + t}$ can resist is $\frac{c r t}{r + t}$, and the strain to which it is actually exposed is $n r$; consequently, when these are equal, we have $n r = \frac{c r t}{r + t}$; from which, by expunging the common factor r, we get

$$n = \frac{c t}{r + t}. \qquad [E]$$

If this value of n be compared with its respective values as indicated in the equations [D] preceding, we shall have the following expressions for the thickness of metal in the cylinder to resist any pressure, while the elastic power of the material remains perfect, namely;—

$$t = \frac{P r}{\cdot 7854\, c\, D^2 - P};\ t = \frac{p r}{\cdot 7854\, c\, d^2 - p},\ \text{and}\ t = \frac{w r}{\cdot 7854\, c\, \delta^2 - w}.$$

Therefore, if for c in each of the preceding expressions we substitute its value as determined by experiment, and which for cast iron, according to Dr. Robison, is 16648 lbs. avoirdupois upon a square inch, then we shall have

$$t = \frac{P r}{13076\, D^2 - P}, \qquad [F]$$

$$t = \frac{p r}{13076\, d^2 - p}, \qquad [G]$$

$$t = \frac{w r}{13076\, \delta^2 - w}. \qquad [H]$$

Where the constant number $13076 = 16648 \times \cdot 7854$.

The following example will illustrate the use of these equations, the value of t the thickness of the metal coming out the same by each.

Ex. 13.—What must be the thickness of metal in the cylinder of a hydrostatic press to resist a pressure of 30000 lbs., the diameter of the cylinder being 5 in., that of the forcing pump 1 in., and of the safety-valve ¼ of an inch, being the same dimensions which we have employed in the preceding examples?

Here we have given $P = 30000$ lbs.; $D = 5$ in.; and consequently, $r = 2\frac{1}{2}$ in.; therefore, by substitution, equation [F] gives $t = \frac{30000 \times 2\frac{1}{2}}{13076 \times 5^2 - 30000} = \cdot 253$ in., being something more than ¼ of an inch.

In order that the entire pressure on the piston of the cylinder may be equal to 30000 lbs. according to the conditions of the question, the force with which the plunger of the forcing pump descends must be equal to 1200 lbs.; therefore by equation [G] we have

$$t = \frac{1200 \times 2\frac{1}{2}}{13076 \times 1^2 - 1200} = \cdot 253 \text{ in., the same as before.}$$

Again, in order that the entire pressure may be equal to 30000 lbs., the weight upon the safety-valve must be 75 lbs.; hence from equation [H] we obtain $t = \frac{75 \times 2\frac{1}{2}}{13076 \times \cdot 25^2 - 75} = \cdot 253$ in., the same as in the two cases foregoing.

It may not be improper here to remark, that although the requisite thickness of metal is alike assignable from either of the above equations, when the respective pressure and diameters are known, yet it is the first of the class only, or that marked [F], which becomes available in practice, and for this reason, that the power of the press, or the aggregate pressure which it is capable of exciting, is known *a priori*, or immediately assignable from the conditions of construction, while the load upon the safety-valve, and the force with which the plunger descends, have each to be determined by calculations founded on circumstances connected with the aggregate or ultimate pressure.

Referring to equation [E], which has been purposely investigated for expressing the intensity

of pressure on a square inch of surface, and multiplying both sides by $r + t$, the denominator of the fraction, we shall have $n r + n t = c t$, from which, by transposing and collecting the terms, we get $(c - n) t = n r$; then by division, the value of t, or the thickness of metal in the cylinder to withstand the pressure, becomes

$$t = \frac{n r}{c - n}. \qquad [K]$$

From which it appears, that if a constant value adapted to practical purposes can be assigned to n, the rule for calculating the thickness of metal in the cylinder will become exceedingly simple.

Now, it has been remarked by several eminent practical engineers, as well as by the most approved and intelligent manufacturers, that the extreme pressure on a square inch of the piston should never exceed half the cohesive power of the material; but, according to Dr. Robison, the cohesive power of cast iron of a medium quality is equal to 16648 lbs.; hence we have

$$n = \frac{16648}{2} = 8324 \text{ lbs.};$$

therefore, if 8324 lbs. be adopted as the limit of pressure upon a square inch of surface, the foregoing value of t becomes $t = \dfrac{8324\,r}{16648 - 8324} = r$. There is no occasion to limit the pressure to the piston only, since every square inch of surface in contact with the fluid sustains the same pressure. This limitation has frequently caused a misapprehension respecting the mode of ascertaining the pressure on an inch of surface.

Consequently, in order that the strain produced by the pressure may not exceed the elastic power of the material,

The thickness of metal ought never to be less than the interior radius of the cylinder.

By the first equation of class [D] it has been shown that the pressure on a square inch of the piston in lbs. avoirdupois is $n = \dfrac{P}{\cdot 7854\,D^2}$, or by substituting the foregoing value of n, it is $8324 = \dfrac{P}{\cdot 7854\,D^2}$; from which, by multiplication, we obtain $8324 \times \cdot 7854\,D^2 = P$; but in order to express the pressure in tons, it is

$$P = \frac{6537 \cdot 6696\,D^2}{2240} = 2 \cdot 9186\,D^2. \qquad [L]$$

Therefore, when the diameter of the cylinder is given, the entire pressure in tons is determined by the following very simple rule.

RULE.—*Multiply the square of the diameter in inches by the constant number* 2·9186, *and the product will be the pressure in tons.*

And again, when the pressure in tons is given, the diameter of the cylinder may be determined by reversing the process, or by the following rule.

RULE.—*Divide the given pressure in tons by the constant number* 2·9186, *and extract the square root of the quotient, for the diameter of the cylinder in inches.*

The preceding theory, as we have developed it, unfolds every particular connected with the hydrostatic press, and by paying proper attention to the equations, rules, and examples, as we have delivered them, every difficulty attending the construction of the instrument will be removed; to practical persons, however, that part of the theory exhibited in the equations marked [K] and [L] will be found the most valuable, as they do the more immediately contain the particulars which direct their operations. The following examples will prove the truth of these remarks.

Ex. 14.—The diameter of the cylinder in a hydrostatic press is 10 in.; what is its power, or what pressure does it transmit?

Here by the first rule above, we have $P = 10^2 \times 2 \cdot 9186 = 291 \cdot 86$ tons.

Ex. 15.—What is the diameter, and what the thickness of metal, in a press of 300 tons power?

By the second rule above, we have $D^2 = 300 \div 2 \cdot 9186 = 102 \cdot 81$ nearly; therefore, by extracting the square root, we obtain $D = \sqrt{102 \cdot 81} = 10 \cdot 13$ in.; consequently, according to the remark under the equation [K], the thickness of metal is $t = 10 \cdot 13 \div 2 = 5 \cdot 065$ in.

The rules by which the preceding examples have been resolved were very nearly, but not precisely, the same as those employed by Joseph and Timothy Bramah in the construction of their excellent presses; the only difference, however, consists in their assuming a higher number as the limit of pressure, the standard which they employed being 8556 lbs. upon a square inch of the piston, thereby indicating that they reckoned on a higher cohesive power in the material than that which we have adopted as the basis of our theory.

Now, 8556 lbs. on a square inch is equivalent to 6619·8824 lbs. upon a circular inch; whereas the constant which we have chosen is only 6537·6696 lbs., being a difference of 82·2128 lbs. upon the circular inch, a difference that need not be regarded in practice, as the error will always fall on the side of safety, giving a smaller power to the press than it really possesses.

It sometimes, indeed it very frequently, happens that presses are constructed without any attention being paid to the relation which subsists between the strength of the parts and the strain which they have to resist; in all such cases, therefore, it may be interesting to possess a

rule by which the merits or demerits of a press so constructed can be ascertained, for in this way a failure in the instrument may be prevented, and a remedy applied to any defect that may exist.

Now, according to the first equation of class [D], the pressure upon a square inch is $n = \frac{P}{\cdot 7854\, D^2}$, and according to equation [E], it is $n = \frac{c\,t}{r + t}$; therefore, by comparison, we have $\frac{P}{\cdot 7854\, D^2} = \frac{c\,t}{r + t}$; consequently, by multiplying and substituting the cohesive power of cast iron, we have $(t + r)\,P = 13076\, D^2\, t$.

Let $4\, r^2$ be substituted in this equation instead of D^2, its equivalent, and we shall obtain $(t + r)\,P = 52304\, r^2\, t$; consequently the pressure in tons is $P = \frac{52304\, r^2\, t}{2240\,(t + r)} = \frac{23 \cdot 35\, r^2\, t}{(t + r)}$.

From which it appears, that by knowing the interior radius of the cylinder and the thickness of the metal, the power of the press can easily be ascertained; the following is the rule for that purpose.

RULE.—*Multiply* 23·35 *times the thickness of metal by the square of the radius of the cylinder, and divide the product by the radius plus the thickness of metal, and the quotient will give the power of the press in tons.*

Ex. 16.—A hydrostatic press is so constructed as to have the interior radius of its cylinder equal to 3 in., and the thickness of metal 4 in.; now this press is designed for packing flax, and is estimated to stand a pressure of 180 tons; query if its power is not overrated?

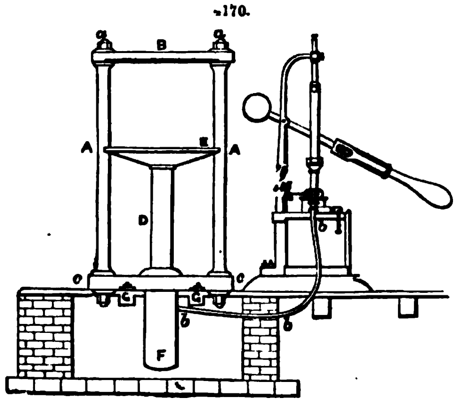
According to the above rule, it is $P = \frac{23 \cdot 35 \times 3^2 \times 4}{4 + 3} = 120 \cdot 08$ tons; consequently the power of the press is overrated by about 60 tons, being one-third less than the estimated pressure according to the question.

The thickness of metal necessary to resist a pressure of 180 tons, or 403200 lbs., is equal to 17·9 in. nearly, and the proposed thickness is only 4 in., being less than one-fourth of the thickness which is really necessary to resist the strain; hence we infer that the press in its present state is entirely unfitted for its intended purpose, and altogether inconsistent with safety and precision of operation.

The hydrostatic press, in its present state of improvement, is a machine that is capable of generating and transmitting a greater degree of force, for the purpose of overcoming immense resistances, and raising enormous loads to a small height, than any other instrument or engine with which we are acquainted; it is therefore of the highest importance that the principles of its construction and the mode of operation should be rightly understood, and in order to render the subject as clear and intelligible as possible, we think proper to lay before our readers the following detailed description.

The woodcut, Fig. 4170, exhibits an elevation of the press in its complete state, accompanied by the forcing pump and all its appurtenances as fitted up for immediate action. F is a strong metallic cylinder of cast iron, or some other material of sufficient density to prevent the fluid from issuing through its pores, and of sufficient strength to preclude the possibility of rupture, by reason of the immense pressure which it is destined to withstand.

4170.



The cylinder F is bored and polished with the most scrupulous precision, and fitted with the movable piston D, which is rendered perfectly water-tight, by means of leather collars constructed for the purpose, and fixed in the cylinder by a simple but ingenious contrivance to be described hereafter.

Into this side or base of the cylinder F, the end of a small tube *b b b* is inserted, and by this tube the water is conveyed or forced into the cylinder; the other end of the tube is attached to the forcing pump, as represented in the diagram.

A A are two very strong upright bars, generally made of wrought iron, and of any form whatever, corresponding to the notches in the sides of the flat table E, which is fixed upon the end of the piston D, and by workmen is usually denominated the follower or pressing table.

B is the top of the frame into which the upright bars A A are fixed, and *c c* is the bottom thereof, both of which are made of cast, in preference to wrought, iron, being both cheaper and more easily moulded into the intended form.

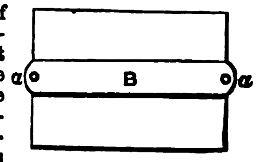
The bottom of the frame *c c* is furnished with four projections or lobes, with circular perforations, for the purpose of fastening it by iron bolts to the massive blocks of wood, whose transverse sections are shown at G G. The top B has two similar perforations, through which are passed the upper extremities of the vertical bars A A, and there made fast, by screwing down the cup-nuts represented at *a* and *a*.

Fig. 4171 represents the plan of the top, or as it is more frequently termed, the head of the frame; the lower side or surface of which is made perfectly smooth, in order to correspond with, and apply to the upper surface of the pressing table E in Fig. 4170; this correspondence of surfaces

becomes necessary on certain occasions, such as the copying of prints, taking fac-similes of letters, and the like; in all such cases it is manifest that smooth and coincident surfaces are indispensable for the purpose of obtaining true impressions.

Fig. 4171 represents the upper side of the block, where it is evident that the middle part B (through whose rounded extremities *a* and *a* the circular perforations are made for receiving the upright bars or rods A A, Fig. 4170) is considerably thicker than the parts on each side of it; this augmentation of thickness is necessary to resist the immense strain that comes upon it in that part; for although the pressure may be equally distributed throughout the entire surface, yet it is obvious that the mechanical resistance to fracture must principally arise from that part, which is subjected to the reaction of the upright bars.

4171.



4173.

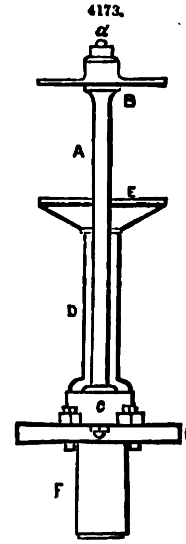
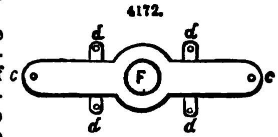
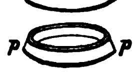


Fig. 4172 represents the plan of the base or bottom of the frame; it is generally made of uniform thickness, and of sufficient strength to withstand the pressure, for be it understood that all the parts of the machine are subjected to the same quantity of strain, although it is exerted in different ways. The upright bars, cylinders, and connecting tubes, resist by tension, the pistons by compression, and the pressing table, together with the top and bottom of the frame, resist transversely.

4172.

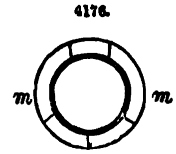


4174.



4175.

4176.



The circular perforations *c c* correspond to *a a* in the top of the frame, and receive the upright bars in the same manner; the perforations *d d d d* receive the screw-bolts which fix the frame to the beams of timber represented at G G, Fig. 4170; the large perforation F receives the cylinder, the upper extremity of which is furnished with a flange, for the purpose of fitting the circular swell around the perforation, and preventing it from moving backwards during the operation of the instrument.

A side view of the engine is represented in Fig. 4173, where the same letters of the alphabet refer to the same parts of the structure.

F is the cylinder into which the fluid is injected; D, the piston, on whose summit is the pressing table E; A, one of the upright rods or bars of malleable iron; B, the head of the press, fixed to the upright bar A by means of the cup-nut *a*; *c*, the bottom, in which the upright bar is similarly fixed; and G a beam of timber supporting the frame with all its appendages.

But the hydrostatic press, as here described and constructed, must not be considered as fit for immediate action; for it is manifestly impossible to bore the interior of the cylinder so truly, and to turn the piston with so much precision, as to prevent the escape of water between their surfaces, without increasing the friction to such a degree that it would require a very great force to counterbalance it.

In order therefore to render the piston water-tight, and to prevent as much as possible the increase of friction, recourse must be had to other principles, which we now proceed to explain.

The piston D is surrounded by a collar of pump-leather *o o*, represented in Fig. 4174, which collar being doubled up, so as in some measure to resemble a lesser cup placed within a greater, it is fitted into a cell made for its reception in the interior of the cylinder; and when there, the two parts are prevented from coming together by means of the copper ring *p p*, represented in Fig. 4175, being inserted between the folds, and retained in its place by a lodgment made for that purpose on the interior of the cylinder.

The leather collar, first arranged in its present form by Benjamin Hick, is kept down by means of a brass or bell-metal ring *m m*, Fig. 4176, which ring is received into a recess formed round the interior of the cylinder, and the circular aperture is fitted to admit the piston D to pass through it, without materially increasing the effects of friction, which ought to be avoided as much as possible.

The leather is thus confined in a cell, with the edge of the inner fold applied to the piston D, while the edge of the outer fold is in contact with the cylinder all around its interior circumference; in this situation the pressure of the water acting between the folds of the leather, forces the edges into close contact with both the cylinder and piston, and renders the whole water-tight; for if the leather be properly constructed and rightly fitted into its place, it is almost impossible that any of the fluid can escape; for the greater the pressure the closer will the leather be applied to both the piston and the cylinder.

The metal ring *m m* is truly turned in a lathe, and the cavity in which it is placed is formed with the same geometrical accuracy; but in order to fix it in its cell it is cut into five pieces by a very fine saw, as represented by the lines in the diagram, which are drawn across the surface of the ring. The four segments which radiate to the centre are put in first, then the segment formed by the parallel kerfs (the copper ring *p p* and the leather collar *o o* being previously introduced), and lastly, the piston which carries the pressing table.

That part of the cylinder above the ring *m m* where the inner surface is not in contact with the

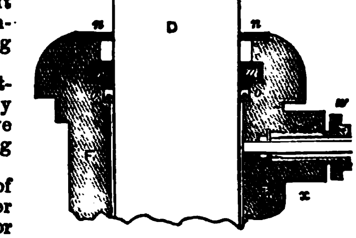
piston is filled with tow or some other soft material of a similar nature; the material thus inserted has a twofold use; in the first place, when saturated with sweet oil, it diminishes the friction that necessarily arises when the piston is forced through the ring $m\,m$; and in the second place, it prevents the admission of any extraneous substance which might increase the friction or injure the surface of the piston, and otherwise lessen the effects of the machine.

The packing here alluded to is confined by a thin metallic annulus, neatly fitted and fixed on the top of the cylinder, the circular orifice being of sufficient diameter to admit of a free and easy motion to the piston.

If a cylinder thus furnished with its several appendages be placed in the frame, and the whole firmly screwed together, and connected with the forcing pump, as represented in Fig. 4170, the press is completed and ready for immediate use; but in order to render the construction still more explicit and intelligible, and to show the method of connecting the press to the forcing pump, let Fig. 4177 represent a section of the cylinder with all its furniture, and a small portion of the tube immediately adjoining, by which the connection is effected.

Then is F F the cylinder; D, the piston; the unshaded parts $o\,o$ the leather collar, in the folds of which is placed the copper ring $p\,p$, distinctly seen but not marked in the figure; $m\,m$ is the metal ring by which the leather collar is retained in its place; $n\,n$, the thin plate of copper or other metal fitted to the top of the cylinder, between which and the plate $m\,m$ is seen the soft packing of tow, which we have described above, as performing the double capacity of oiling the piston and preventing its derangement.

4177.



The combination at $w\,x$ represents the method of connecting the injecting tube to the cylinder; it may be readily understood by inspecting the figure; but in order to remove all causes of obscurity it may be explained in the following manner.

The end of the pipe or tube, which is generally made of copper, has a projecting piece or socket flange soldered or screwed upon it, which fits into a perforation in the side or base of the cylinder, according to the fancy of the projector, but in the figure before us the perforation is in the side.

The tube thus furnished is forcibly pressed into its seat by a hollow screw w, called a union screw, which fits into another screw of equal thread made in the cavity of the cylinder; the joint is made water-tight by means of a collar of leather, interposed between the end of the tube and the bottom of the cavity.

A similar mode of connection is employed in fastening the tube to the forcing pump, the description of which, although it constitutes an important portion of the apparatus, does not properly belong to this place; the principles of its construction and mode of action must therefore be supposed as known, until we come to treat of the construction and operation of pumps in general.

Admitting therefore that the action of the forcing pump is understood, it only now remains to explain the nature of its operation in connection with the hydrostatic press, the construction of which we have so copiously exemplified.

In order to understand the operation of the press, we must conceive the piston D, Fig. 4170, as being at its lowest possible position in the cylinder, and the body or substance to be pressed placed upon the crown or pressing table E; then it is manifest that if water be forced along the tube $b\,b\,b$ by means of the forcing pump, it will enter the chamber of the cylinder F immediately beneath the piston D, and cause it to rise a distance proportioned to the quantity of fluid that has been injected, and with a force determinable by the ratio between the square of the diameter of the cylinder and that of the forcing pump. The piston thus ascending carries its crown, and consequently the load along with it, and by repeating the operation more water is injected, and the piston continues to ascend till the body comes into contact with the head of the frame B, when the pressure begins; thus it is manifest that by continuing the process the pressure may be carried to any extent at pleasure; but we have already stated, in developing the theory, that there are limits beyond which, with a given bore and a given thickness of metal, it would be unsafe to continue the strain.

When the press has performed its office, and it becomes necessary to relieve the action, the discharging valve placed in the furniture of the forcing pump must be opened, which will admit the water to escape out of the cylinder and return to the cistern, while the table and piston, by means of their own weight, return to their original position.

Friction of the Collar.—There had long been a lack of trustworthy information on the friction of the leather collars in hydraulic presses, until John Hick, C.E., of Bolton, carried out a series of valuable experiments, which furnished the following results;—

The friction increases as the pressure increases.

The friction of the leathers for rams of different diameters, if the pressure to the unit of area be the same, increases in direct proportion with the diameters, or with the square roots of the respective gross loads.

The depth of the leather does not affect the friction on the ram. In several of the experiments the leathers were cut after the first trial to half the depth, and after the second trial to one-quarter the original depth, and the results, in all three cases, were practically the same. This led to the belief that the water pressing against the sides of the ram produces a friction equal to that produced by the leather to the unit of area acted upon by the water. New cylinders were therefore tried, in which double the length of ram was opposed to the pressure, and the friction was again the same. It is thus evident that the depth of the leather and the length of ram in the cylinder have very little, or practically no influence on the total friction. In fact, it appears that the

whole friction is produced just where the leather emerges from the hollowed part of the groove and begins to lean against the ram.

The experiments made with leather collars for a ram 4 in. in diameter, the leather being quite new and stiff and sparingly lubricated, show the greatest friction to be 1·55 per cent. of the pressure on the area of 12·56 sq. in., and the smallest friction as 1·07 per cent. If we take 1·5 per cent. for a 4-in. ram under these unfavourable circumstances, we are quite on the safe side. Forty-eight experiments made with leather collars used before, and well lubricated, give an average friction of 0·72 per cent. of the pressure on a ram of 4 in. diameter. In some of these experiments the friction was as high as 1 per cent., in others as low as 0·5 per cent., the variations being 0·5 per cent.

Thirty-four experiments with a ram 8 in. diameter show the friction to be, on an average, 0·395 per cent. of the pressure on the area of 50·26 sq. in. In some of these experiments the friction was as high as 0·52 per cent., whilst in others it was as low as 0·26, the variations being only about one-fourth per cent.

If we therefore take the friction of leather collars for hydraulic presses, or other hydraulic machinery in good working condition, as 1 per cent. for rams of 4 in. diameter, or as 0·5 per cent. for rams of 8 in. diameter, we may be certain that this will meet the generality of cases.

From the experiments is deduced the following formula ;—$F = D \times P \times c$, in which F = total friction of leather collar; D = diameter of ram in inches; P = pressure to the square inch; C = a coefficient; $C = 0·0471$ if leathers new or badly lubricated; $C = 0·0314$ if leathers in good condition and well lubricated. Where the pressure is given to the circular inch the formula becomes;—$F = D \times P_o \times C_o$, in which F = total friction of leather collar; D = diameter of ram in inches; P_o = pressure to the circular inch; C_o = a coefficient; $C_o = 0·06$ if sparingly lubricated; $C_o = 0·04$ if well lubricated.

It may be well to select an example or two, in order to render the foregoing perfectly clear.

First Example.—The friction of a leather collar of a 12-in. ram with a pressure of 5000 lbs. to the square inch;—$F = 12 \times 5000 \times 0·0314 = 1884$ lbs. if well lubricated. The total pressure on a 12-in. ram is $= 113 \times 5000 = 565000$ lbs.; and the friction, as found above, $1884 \div 565000 = 0·0033$, or one-third per cent.

Second Example.—The friction of the leather of a 5-in. ram, with 6500 lbs. pressure to the circular inch;—$F = 5 \times 6500 \times 0·04 = 1300$ lbs. The total pressure on the 5-in. ram $= 25 \times 6500 = 162500$ lbs.; and the friction, as found above, $1300 \div 162500 = 0·008$, or eight-tenths per cent.

The annexed Table gives, in a compact and convenient form, the frictional resistance in percentage of the total hydraulic pressure for rams from 2 in. up to 20 in. in diameter.

D, Inches.	F, per Cent.	D, Inches.	F, per Cent.	D, Inches.	F, per Cent.	D, Inches.	F, per Cent.
2	2·00	7	0·57	12	0·33	17	0·23
3	1·33	8	0·50	13	0·30	18	0·22
4	1·00	9	0·44	14	0·28	19	0·21
5	0·80	10	0·40	15	0·26	20	0·20
6	0·66	11	0·38	16	0·25		

FRICTION OF LEATHER WASHER FOR RAM ½ IN. DIAMETER.

Leather Washer, new and stiff.			Leather used before.		Second Leather.	
Gross Load on Ram ½ in. diam.	Friction of Washer.	Friction in percentage of Gross Load.	Friction in lbs.	Friction in percentage.	Friction in lbs.	Friction in percentage.
lbs.	lbs.					
50	13	26·0	9·0	18·0	9	18·0
100	12·5	12·5	8·5	8·5	13	13·0
150	18	12·0	11·5	7·6	15	10·0
200	20	10·0	13	6·5	20	10·0
250	23	9·6	13·5	5·4	23	9·6
300	27	9·0	14·7	4·9	27	9·0
350	18	5·1	15·4	4·4	29	8·2
400	23	5·6	16·5	4·1	31	7·7
450	26	5·7	18	4·0	34	7·5
500	25	5·0	19	3·8	37	7·4
600	26	4·3	20	3·3	38	6·3
700	32	4·5	23·3	3·3	44	6·2
800	38	4·7	24	3·0	45	5·6
900	35	3·9	28	3·1	48	5·3
1000	33	3·3	33	3·3	48	4·8
1100	40	3·6	35·2	3·2	48	4·3
1200	50	4·1	40·8	3·4	50	4·1
1300					50	3·8

FRICTION OF LEATHER COLLAR FOR RAM 4 IN. DIAMETER. LEATHER NEW AND STIFF; SPARINGLY LUBRICATED.

Net Pressure on ½-in. Ram.	Equivalent Pressure a square inch.	Pressure on 4-in. Ram.	Friction of Leather in lbs.	Friction in percentage of Load.
lbs.	lbs.	lbs.		
37	188·7	2,368	110	4·6
87·5	446·2	5,600	117	2·0
132	673·2	8,448	125	1·48
180	918	11,520	130	1·12
227	1157·7	14,528	171	1·17
273	1392·3	17,472	214	1·22
332	1693·2	21,248	228	1·07
377	1922·7	24,128	280	1·16
424	2162·4	27,136	334	1·23
475	2422·5	30,400	389	1·27
574	2927·4	36,736	459	1·25
668	3406·8	42,752	543	1·26
762	3886·2	48,768	641	1·31
865	4411·5	55,360	753	1·36
967	4931·7	61,888	823	1·33
1060	5406	67,840	1047	1·54
1150	5865	73,600	1147	1·55
Average percentage of 15 =				1·28

FRICTION OF LEATHER COLLAR FOR RAM 4 IN. DIAMETER. LEATHER WELL LUBRICATED.

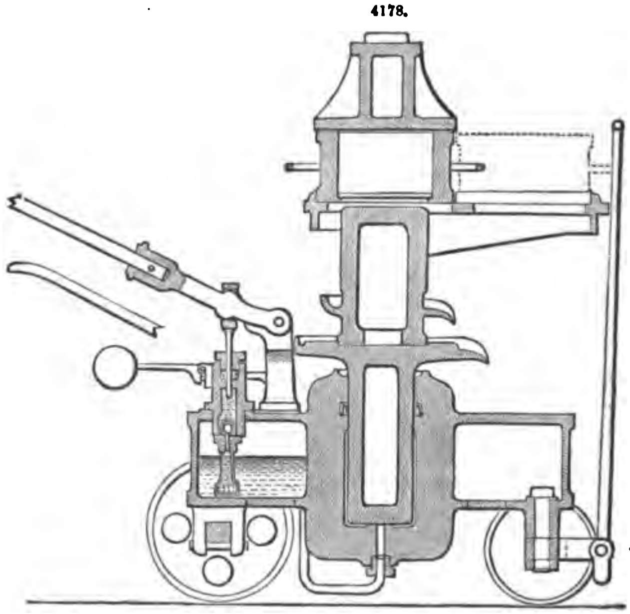
Depth of Leather touching Ram.			¼-in.		½-in.		¾-in.	
Net Pressure on ½-in. Ram.	Equivalent Pressure a square inch.	Pressure on 4-in. Ram.	Friction of Leather in lbs.	Friction in percentage of Load.	Friction of Leather in lbs.	Friction in percentage of Load.	Friction of Leather in lbs.	Friction in percentage of Load.
lbs.	lbs.	lbs.						
41	209·1	2,624	56	2·13	87	1·40	39	1·50
87	443·7	5,568	70	1·25	52	0·94	70	1·25
135	688·5	8,640	80	0·95	78	0·91	80	0·92
180	918·0	11,520	84	0·72	100	0·87	85	0·73
227	1157·7	14,528	88	0·60	116	0·80	92	0·63
273	1392·3	17,472	93	0·53	162	0·92	105	0·60
321	1637·1	20,544	103	0·50	174	0·84	125	0·60
369	1881·9	23,616	123	0·52	189	0·80	140	0·59
419	2136·9	26,816	140	0·52	214	0·79	154	0·57
463	2361·3	29,632	156	0·52	226	0·76	168	0·56
562	2871·2	35,968	176	0·49	244	0·67	180	0·50
651	3320·1	41,664	231	0·55	280	0·67	231	0·55
755	3850·5	48,320	312	0·64	374	0·77	280	0·58
852	4345·2	54,528	335	0·61	420	0·77	305	0·56
952	4855·2	60,928	375	0·61	493	0·81	360	0·59
1052	5365·2	67,328	432	0·63	558	0·83	390	0·58
1150	5865·0	73,600	520	0·70				
1250	6375·0	80,000	660	0·75				
Average percentage of 16 =				0·61		0·846		3·706

FRICTION OF LEATHER COLLAR FOR RAM 8 IN. DIAMETER.

			Leather new and sparingly lubricated.		Leather used before, well lubricated.	
Net Pressure on ½-in. Ram.	Equivalent Pressure a square inch.	Pressure on 8-in. Ram.	Friction in lbs.	Friction in percentage of Load.	Friction in lbs.	Friction in percentage of Load.
lbs.	lbs.	lbs.				
87	443·7	22,272	102	0·46	94	0·42
135	688·5	34,560	162	0·47	145	0·42
180	918·0	46,080	207	0·45	180	0·39
227	1157·7	58,112	255	0·44	186	0·32
273	1392·3	69,888	321	0·46	216	0·31
321	1637·1	82,176	385	0·47	271	0·33
369	1881·9	94,464	415	0·44	274	0·29
419	2136·9	107,264	547	0·51	290	0·27
463	2361·3	118,528	569	0·48	355	0·30
562	2871·2	143,872	690	0·48	374	0·26
651	3320·1	166,656	866	0·52	433	0·26
755	3850·5	193,280	889	0·46	560	0·29
852	4345·2	218,112	1047	0·48	590	0·27
952	4855·2	243,712	1121	0·46	682	0·28
1052	5365·2	269,312	1320	0·49	862	0·32
1150	5865·0	294,400	1475	0·50	942	0·32
1250	6375·0	320,000	1600	0·50	1056	0·33
Average percentage of 17 =				0·474		0·316

Portable Hydraulic Press.—Fig. 4178 shows a section of an improved hydraulic hand-press, by Gwynne and Co., Essex Street Works, London. This press can be used for expressing oil from linseed, rape, cotton, colza, poppy, or other seeds, and is a very convenient arrangement, well suited for India and the colonies. The machine consists of a cylinder 7 in. diameter, with 1-inch ram. On the top of the ram is cast a receiver with a lip, into which the oil runs after being pressed out of the seeds. The top of the ram is also fitted with an arrangement for taking two boxes; much time is thus saved by filling one while the other is under pressure.

4178.



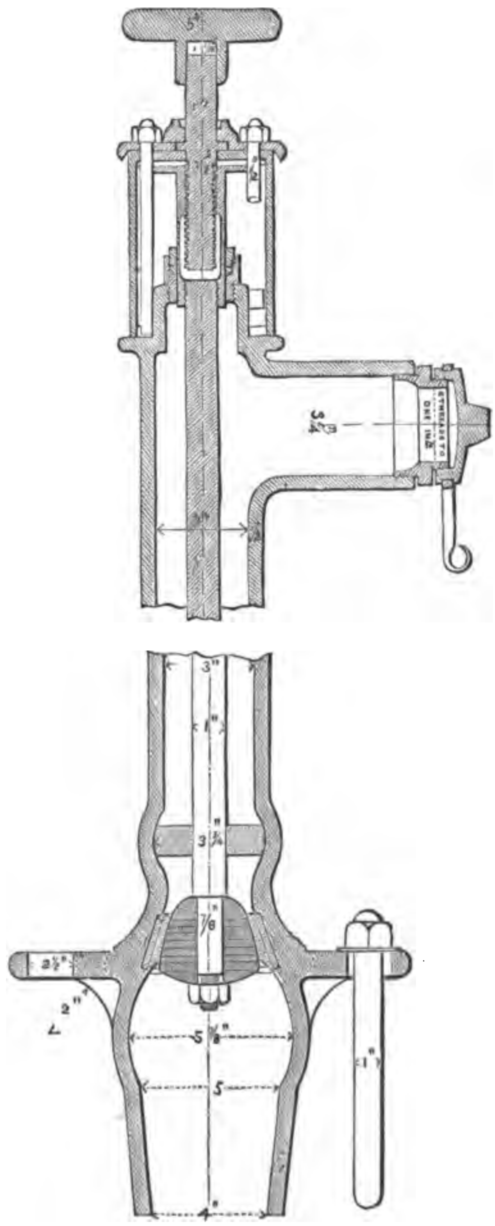
The ram is worked by a small hydraulic pump of gun-metal, fitted on to the tank, which also forms the base of the press. The pump is fitted with pressure-gauge and self-acting safety-valve; the lever handle is made in two pieces for convenience of travelling, and the machine is rendered portable by being erected upon a carriage fitted with wheels and handle. The weight of the whole is about 16 cwt.; it will give a pressure of about 60 tons, and, with one press-box, will press about 1½ bushel of seed an hour.

Hydrant.—A hydrant is a pipe or spout at which water may be drawn from the mains of an aqueduct; it is, in fact, a large water-plug. Fig. 4179 is a section of one of the hydrants used in the city of Brooklyn, U.S. Upwards of eight hundred hydrants are in use in that city, distributed

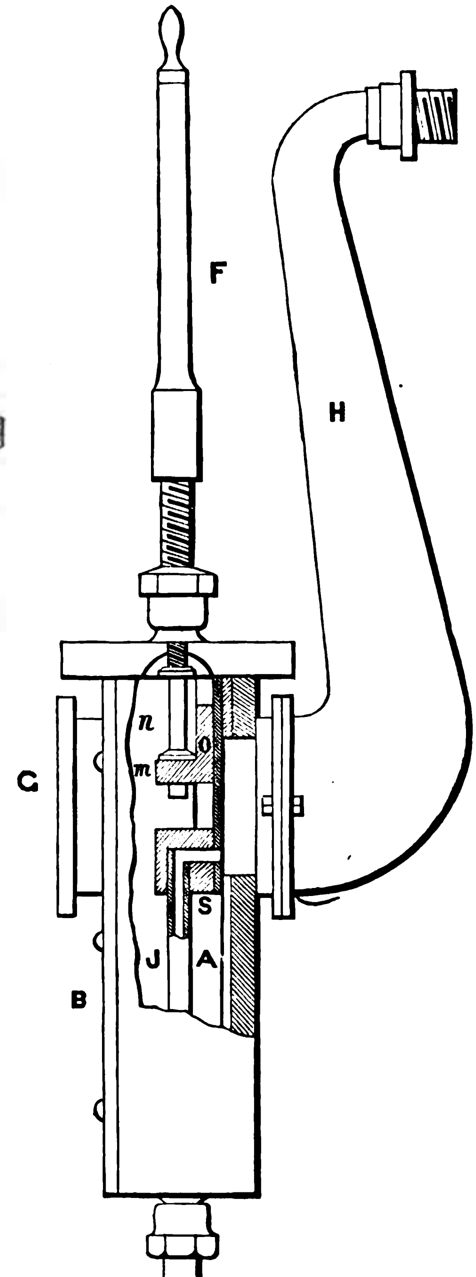
over 120 miles of pipes. Although the diameter of these pipes varied from 6 to 36 in., 4-in pipes were exclusively used to connect the hydrants with the street pipes.

Fig. 4180 relates to a simply-constructed hydrant invented by Wm. Kearney, Union Township, N.J. A B is the case; O, a sliding disc-valve perforated at S; F, screw stem; H, the nozzle;

4179.



.4180.



J, discharge-pipe; n, valve-rod; G m, supply-pipe. The valve O is operated by means of the screw stem, which admits the water, while a cavity on the lower edge opens a communication between the discharge and waste pipes.

See AIR-CHAMBER. CROWBAR. DRAINAGE. ENGINES, VARIETIES OF. PUMPS AND PUMPING ENGINES.

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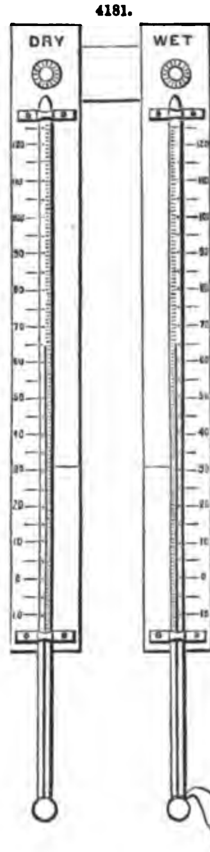
HYDROMETER. Fr., *Hydromètre;* Ger., *Hydrometer;* Ital., *Idrometro;* Span., *Hidrómetro.* See Saccharometer.

HYGROMETER. Fr., *Hygromètre;* Ger., *Hygrometer;* Ital., *Igrometro;* Span., *Higrómetro.*

A hygrometer is an instrument for measuring the degree of moisture of the atmosphere. It is principally used for meteorological purposes, but it is also of great service in determining the degree of humidity of the air in certain manufactories and in conservatories. The form of the instrument employed for this purpose is known as Mason's Dry- and Wet-Bulb Thermometer, Fig. 4181, which consists of two thermometers, as nearly as possible identical, the one marked dry, the other wet. The bulb of the wet thermometer is covered with thin muslin, round the neck of which and over the muslin is twisted loosely, or tied in a loose knot, a conducting thread of lamp-wick, common darning-cotton, or floss silk; this passes to an adjacent vessel of water placed at such a distance as to allow a length of conducting thread of about three inches. The reservoir of water should be placed on one side and a little beneath, so that evaporation from the water may not affect the reading of the dry bulb by its too near vicinity. Before use, the cotton lamp-wick should be washed in a solution of carbonate of soda, and pressed whilst under water throughout its length. In use it should be of such extent that the water conveyed be sufficient in quantity to keep the muslin on the bulb as moist as when the air is saturated with vapour. The amount of water supplied can be increased or diminished by increasing or decreasing the extent of the conducting thread. The temperatures of the air and of evaporation are given by the readings of the two thermometers.

4181.



ICE-MAKING MACHINE. Fr., *Congelateur;* Ger., *Eismaschine;* Ital., *Macchina da far ghiaccio.*

Ice acts as a cooling agent in virtue of the physical fact that, in common with all solid substances, it requires an expenditure of heat for its conversion into the liquid state. The heat thus applied does not produce any elevation of temperature, but as the ice melts it disappears, so far as the indications of the thermometer will show, and there remains a quantity of water of the same temperature as the ice itself. Thus when ice or snow is mixed with three-fourths its weight of boiling water, the water remaining after the ice has melted has a temperature of 32° Fahr., the same as the ice itself; the quantity of heat in the boiling water, corresponding to the interval of temperature between 32° and 212° Fahr., having been rendered latent, or expended in effecting the liquefaction of the ice. It is in this way that ice cools water, air, or any other substance it is brought in contact with which has a temperature higher than 32° Fahr. Hence refrigeration is simply a manipulation of heat. It is an operation in this respect perfectly analogous to the production of a high temperature, in so far as both processes consist in the transfer of heat from one substance to another, and are subject to the same general laws. They are, however, reverse processes. Thus in generating steam, heat produced by the combustion of fuel is communicated to water. In making ice, on the contrary, heat is abstracted from water, and in this process the water which is cooled corresponds to the fuel burnt in generating steam, or in converting any other substance into vapour. Just in the same way that the fuel in burning yields its heat to the substance vaporized, so does the water, in making ice, yield its heat to some other substance capable of receiving it.

This is the nature of the work to be done in making ice, and it is now necessary to consider the amount of that work requisite for producing a given quantity of ice.

Water at the temperature of 60° Fahr. contains an amount of heat greater than that contained in an equal weight of ice at 32° Fahr. to the extent of 170·65 heat units for each pound, con-

sequently to convert water at 60° Fahr. into ice, it is necessary to abstract that amount of heat from it. Thus to produce a ton of ice the quantity of heat to be abstracted from water at 60° Fahr. amounts to

$$\underset{\text{Heat units.}}{382256} = \underset{\text{lbs.}}{2240} \times 170{\cdot}65.$$

This is a quantity of heat not more than about one-eightieth part of that capable of being generated by the combustion of a ton of ordinary coal.

The means by which this amount of heat may be abstracted from water consist in producing some physical change involving an expenditure of heat, and doing this in such a way that the heat required for, and applied to that purpose, is abstracted from the water to be cooled and frozen. The conversion of any substance into vapour is a change of this kind, which involves an expenditure of heat similar to that taking place in the melting of ice. The amounts of heat thus absorbed by various substances in vaporizing are as follows;—

	Latent heat a lb. Heat units.	Authority.
Water	966·1	Regnault.
Liquid ammonia	900·0	Favre and Silbermann.
Alcohol	364·3	Andrews.
Ether	162·8	Andrews.

The amount of heat thus disposed of and rendered latent in the formation of steam from water is considerably greater than that existing in the latent condition in liquid water, or, what amounts to the same thing, that expended in melting ice; but the vaporization of water cannot be applied as a means of refrigeration to any great extent, because under the ordinary atmospheric pressure it does not take place readily or with sufficient rapidity at temperatures much below the normal boiling-point, or 212° Fahr., and even when the pressure is removed by means of an air-pump, the vaporization of water proceeds very slowly at low temperatures. There are, however, other substances which vaporize readily under these conditions; and, for this reason, they are specially suited for artificial refrigeration, although the amounts of heat expended and rendered latent in their vaporization are less than in the case of water. Ether, alcohol, and liquid ammonia are substances of this kind; and, according to the foregoing data, expressing the latent heat of their vapours, the quantities of each of these substances which would have to be vaporized, in order to produce a ton of ice from water at 60° Fahr., or to produce a refrigeration equivalent to the melting of a ton of ice, would be;—

	lbs.
Ether	2348·009
Alcohol	1049·272
Liquid ammonia	424·728

From this comparison it will be seen that the expenditure of heat accompanying the vaporization of liquid ammonia is much greater than it is in the case of alcohol or ether, and that in this respect it is the most powerful as a refrigerating agent. But the amount of heat rendered latent in the vaporization of any substance is not the chief point which determines its efficiency as a refrigerating agent. The degree of facility with which a substance vaporizes at low temperatures is of still greater importance, as will be evident from the following Table, which gives the tension of the vapours at different temperatures below the boiling-points of the liquids under normal atmospheric pressure.

		Ammonia.	Ether.	Alcohol.	Water.
Normal Boiling-point.		28°	95°	172°	212° F.
	° Fahr.	inches.	inches.	inches.	inches.
Tension of vapour in inches of mercury at	104	463·64	85·81	5·26	2·16
	68	254·61	17·06	1·75	·68
	50	181·58	11·28	·96	·36
	32	124·52	7·22	·50	·18
	− 4	55·03	2·66	·13	
	− 40	20·81			
	− 109	9·45			

Since the tension of a vapour at any temperature is the measure of the facility with which the liquid evaporates at that temperature, it will be seen from the data in this Table that in this respect there is a very considerable difference between the liquids there named. Here, again, the characters of liquid ammonia are such as to give it a marked precedence over all the other liquids, as a refrigerating agent, by reason of its relative capability of vaporizing at very low temperatures. This substance is in fact gaseous under normal pressure, within the ordinary range of atmospheric temperature, the boiling of the liquid being many degrees below the zero of Fahrenheit's scale; and at ordinary temperatures it requires a pressure of from eight to ten atmospheres—117 to 150 lbs. a square inch—to maintain it in the liquid state.

Alcohol, although it has a greater capability than ether of absorbing heat in vaporizing, is still inferior to ether as a refrigerating agent, on account of its being much less readily vaporized at low temperatures: and even ether evaporates so slowly at temperatures much below its normal boiling-

point, that it can be used for refrigerating only with the aid of an air-pump to maintain the requisite rate of vaporization.

Liquid ammonia is therefore by far the most efficient material to use for this purpose, not only on account of its ready vaporization at low temperatures, but also because its power of absorbing heat in that change is but little inferior to that of water.

Another process, in which heat is expended and rendered latent, is the expansion of air. The amount of heat thus absorbed is at the rate of ·069, or about $\frac{1}{16}$th of a heat unit for each pound of air expanded to the extent of ·002035, or about $\frac{1}{490}$th of its volume at 32° Fahr. under normal pressure. If therefore air be compressed, say to one-tenth of its bulk, and, after being cooled to a low temperature, it be allowed to expand in such a way as to perform mechanical work, such as moving a piston, there is an expenditure of heat proportional to the resistance overcome and to the degree of expansion. Consequently the temperature of the gas is reduced during the act of expansion, and this effect may be taken advantage of for purposes of refrigeration. The chief disadvantage of this method consists in the great expenditure of power requisite for compressing the air, which involves a large consumption of fuel.

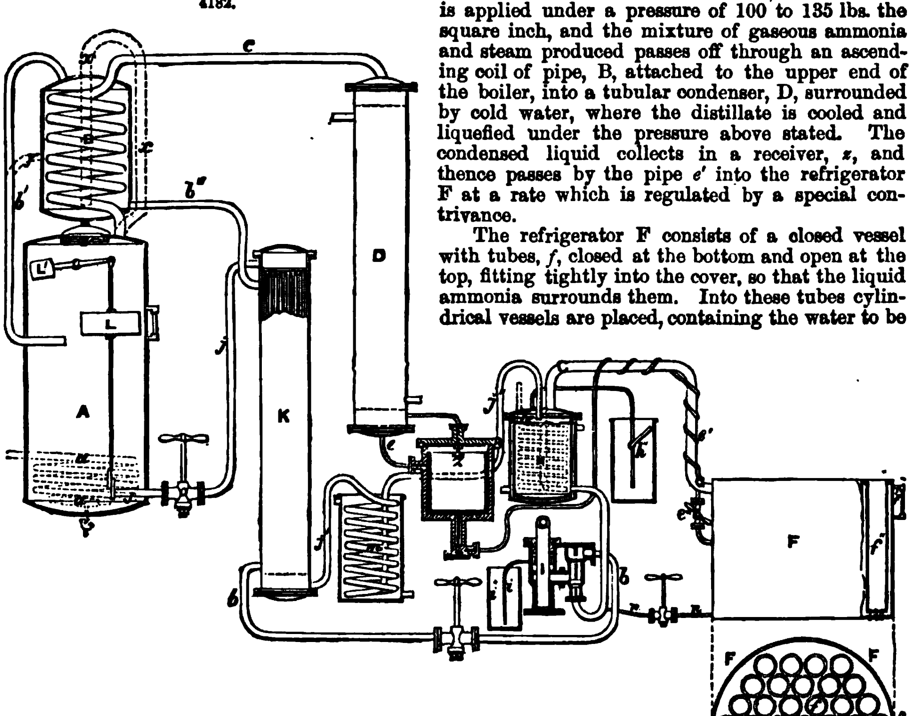
From what has been stated, it will be apparent that at present the choice of a refrigerating agent for producing ice or great degrees of cold lies between ammonia, ether, and air, and that ammonia presents the greatest advantages for this purpose.

The expansion of compressed air appears to have been the means first adopted for making ice, by Dr. Gorrie, of America; and in this country ether was the material employed in one of the earliest ice-making machines invented by Harrison, in 1856.

The fundamental principles on which this apparatus was constructed were correct, but there appears to have been several serious errors made in their application, and the plan did not come into use in this country. The ether machine was afterwards improved by Messrs. Siebe in 1862, and they have since employed themselves specially to the manufacture of these ice machines. Most of those which have been made were for India and other hot climates, where it has been found more advantageous to make ice by artificial refrigeration than to import it from America, owing to the large amount of waste by melting during the voyage through warm latitudes.

In the year 1860 another apparatus was invented by M. Carré, of Paris, in which a very strong solution of ammonia was used as the refrigerating agent. The arrangements of this apparatus provided for the condensation of the ammonia vaporized in the refrigerator, in such a way that it was used over and over again, and the operation of the apparatus was continuous, as in the case of the ether machine. Fig. 4182 represents this apparatus. A strong, vertical boiler, A, is charged with a concentrated solution of ammonia, to which heat is applied under a pressure of 100 to 135 lbs. the square inch, and the mixture of gaseous ammonia and steam produced passes off through an ascending coil of pipe, B, attached to the upper end of the boiler, into a tubular condenser, D, surrounded by cold water, where the distillate is cooled and liquefied under the pressure above stated. The condensed liquid collects in a receiver, *x*, and thence passes by the pipe *e'* into the refrigerator F at a rate which is regulated by a special contrivance.

4182.

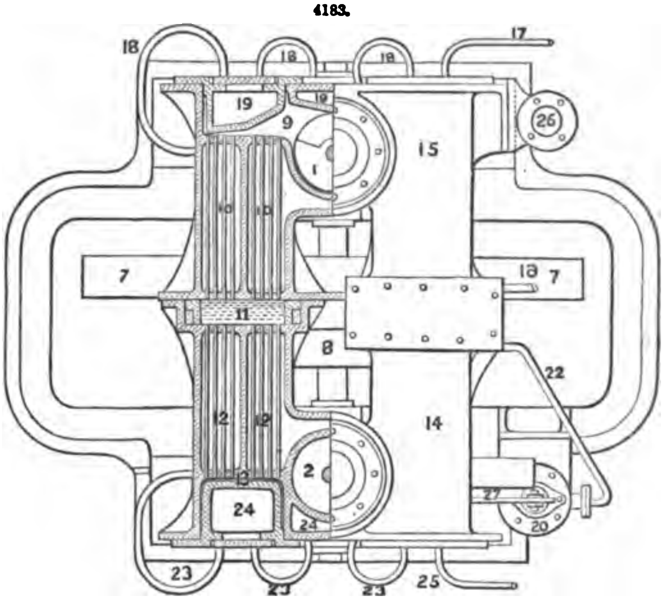


The refrigerator F consists of a closed vessel with tubes, *f*, closed at the bottom and open at the top, fitting tightly into the cover, so that the liquid ammonia surrounds them. Into these tubes cylindrical vessels are placed, containing the water to be frozen. The upper end of the refrigerator is connected by means of a pipe, G, with a vessel, H, within which the gaseous ammonia discharged from the refrigerator comes in contact with a continuous supply of cold water, and is thereby absorbed, while the solution of ammonia produced is removed from the bottom of the vessel H by the pump I. In this way the gaseous ammonia is

removed from the refrigerator and the pressure kept so low that the liquid ammonia is vaporized continuously, thereby abstracting heat from the contents of the tubes *f*.

The solution of ammonia produced in the absorber H is forced by the pump I through the pipe *b* into the outer casing of a tubular vessel, K, called the regenerator, through the tubes of which hot water exhausted of ammonia flows in the opposite direction from the boiler A. Here an interchange of temperature takes place, the solution of ammonia becoming heated while the exhausted liquor is cooled. The solution of ammonia thus heated then passes on into the closed vessel above the boiler and containing the coil B, where it is still further heated, while the gaseous ammonia and steam within the coil B are partially cooled and condensed, and it then flows by the pipe *b'* into the boiler A, to serve for a repetition of the process.

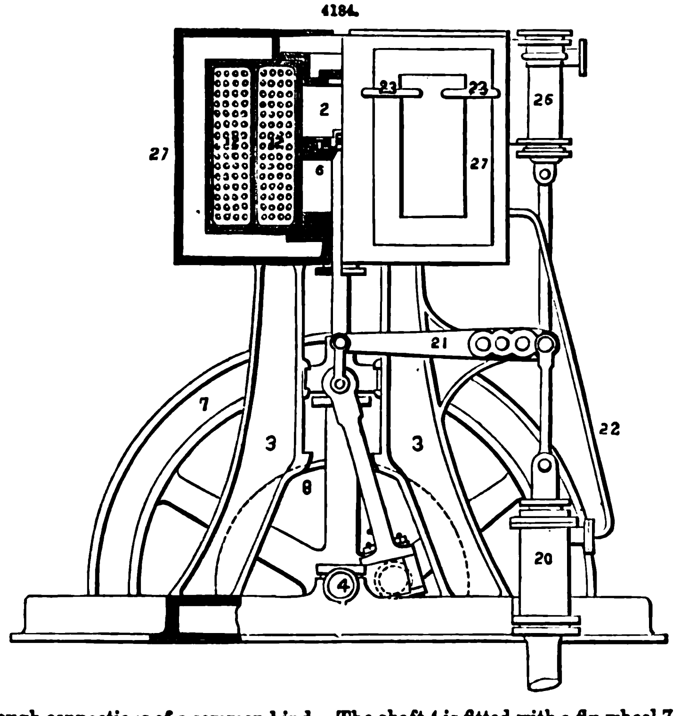
4183.



The hot liquor exhausted of ammonia meanwhile flows from the boiler in a regulated current through the pipe J into the tubes of the regenerator K, thence through a cooling worm, *m*, surrounded by water, where its temperature is sufficiently reduced, and then passes into the absorber H, furnishing the supply of water for dissolving the ammonia as already described.

This machine has been largely used in the south of France for effecting the crystallization of salts by cooling, and several have been sent out to India for making ice.

4184.



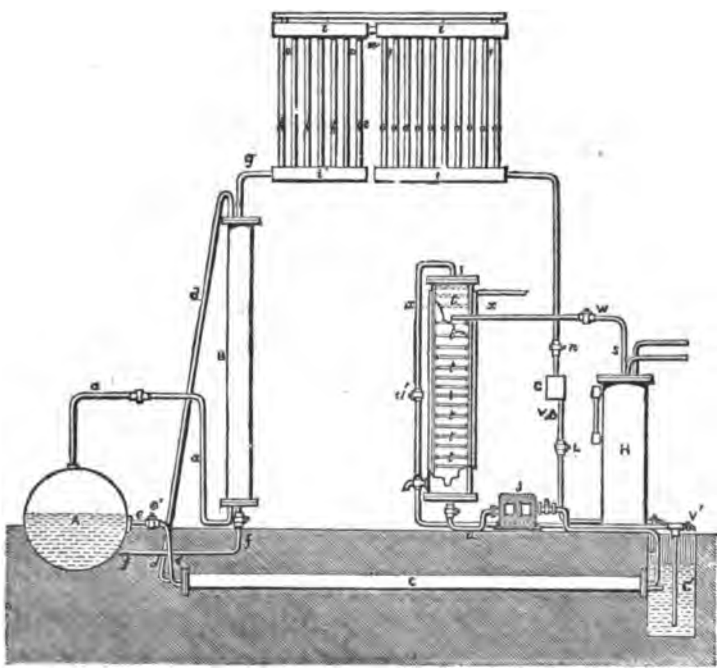
In 1862 A. C. Kirk invented a machine in which the alternate compression and expansion of air was applied as the means of refrigeration. The arrangement of the machine was very good; but for making ice it was expensive, on account of the relatively large expenditure of power required. Kirk has, however, recently introduced another form of his machine, which seems better adapted to refrigerate economically.

Fig. 4183 is a plan partly in horizontal section, Fig. 4184 an end elevation partly in vertical section, of this improved apparatus. It comprises two vertical cylinders 1, 2, each formed in the same casting, with casings containing accessory spaces and passages, and mounted in an inverted position on frame standards 3 over the crank shaft 4, by which their pistons 6 are actuated through connections of a common kind. The shaft 4 is fitted with a fly-wheel 7 and with a pulley 8, the latter receiving a driving belt from a convenient prime mover. The cylin-

ders 1, 2, have ports at both ends, and one half of Fig. 4183 represents the section as at the level of the lower ports, but only the port 9 of one cylinder 1 is seen, as the lower port of the other cylinder 2 is at the other side. From the bottom of cylinder 1 the air can pass through the port 9, thence through a set of tubes 10 to a regenerator 11, the other side of which communicates through a second set of tubes 12 with a space 13 having at its upper end a port leading into the top of the other cylinder 2. This space 13 is very narrow at the level of the section, but increases in width upwards. The bottom of cylinder 2 communicates through similar parts in the casings 14, 15, with the top of cylinder 1. The spaces crossed by the tubes 10 and those in the casing 15 are occupied and traversed by the water or other liquid used to abstract heat from the compressed air, such water entering by a pipe 16, and being discharged by a pipe 17, first however being led by means of pipes 18 through spaces 19 formed at the outer sides of the cylinder ports 9. A pump 20 worked by a lever 21 connected to one of the piston-rod slide-blocks is used for forcing the liquid to be cooled through the apparatus, and this liquid passes by a pipe 22 into the casing 14 crossed by tubes, passing thence to the space crossed by the tubes 12, and through pipes 23 and spaces 24 to the outlet-pipe 25, it being preferable to employ in the apparatus air which in its most expanded state therein is of a greater than atmospheric pressure. A force-pump 26 is provided for forcing in air to compensate for any leakage, being arranged to be worked by means of a lever connected to one of the piston-rod slide-blocks. The pipes for leading the air from the pump to the interior of the apparatus are not shown, but may be arranged in any convenient way in communication with the top and the bottom of either cylinder, provision being made as usual for drying the air so forced in. The cylinder 2 and the parts in connection with it in which the compressed air expands are shown in Fig. 4184 as enclosed in an outer casing 27, to prevent as far as possible the communication of heat from the atmosphere, and the jacket space enclosed by this casing is to be filled with any suitable non-conducting substance.

An improved form of the ammonia apparatus, which comprises some novel features of very great importance in regard to the use of that material for refrigeration, was invented by Mr. Reece in 1867. The arrangement of this apparatus is shown by Fig. 4185. The boiler A is charged

4185.



with water or a very weak solution of ammonia, and the steam, discharged under a pressure of 100 lbs. to the square inch, passes by the pipe *a a* to the bottom of a Coffey's analyzer B, consisting of a tall columnar vessel with a series of plates arranged one above the other inside. Into the top of this vessel a concentrated solution of ammonia is pumped continuously, and in descending from plate to plate it meets the ascending current of high-pressure steam, the effect of their contact being to convert the ammonia into gas, while the steam is condensed and flows back again to the boiler A. The gaseous ammonia passes out of the analyzer by the pipe *g* into a tubular rectifier D D, where the remaining steam is condensed and separated, while the ammonia passes on through a condenser F F, where it is liquefied, and then flows through a pipe to the refrigerator H, the supply being regulated by a cock *n*.

Meanwhile a regulated current of spent liquor passes from the boiler into a long tube, C, called the heater, fitted with an internal set of tubes, through which the concentrated solution of

ammonia is forced by the pump J into the top of the analyzer. By this means the solution of ammonia is heated, and at the same time the hot liquor from the boiler is sufficiently cooled to be supplied to the absorber I, into which it is forced by the pressure of the boiler, through the pipe *x*, fitted with a cock *w*, to regulate the supply. In the absorber I this water becomes saturated with gaseous ammonia discharged from the refrigerator H, and the resulting strong solution of ammonia is then pumped out into the analyzer.

The important feature of this arrangement consists in the application of the analyzing column B, and the rectifier D D, by which it is intended that the dehydration of the ammonia should be carried so far that the condensed liquid passing into the refrigerator may be practically free from water, while in Carré's apparatus the liquid supplied to the refrigerator contains 25 per cent. of water, and only 75 per cent. of actual ammonia.

Many attempts have been made to utilize for the production of cold the well-known principle of the lowering in temperature of a gas, air for example, when it dilates in exercising an exterior pressure. The comparative failures of these attempts have been caused by the insufficiency of the means employed to destroy the heating of the air occasioned by its compression, for this is the great difficulty to be overcome before the principle can be made use of.

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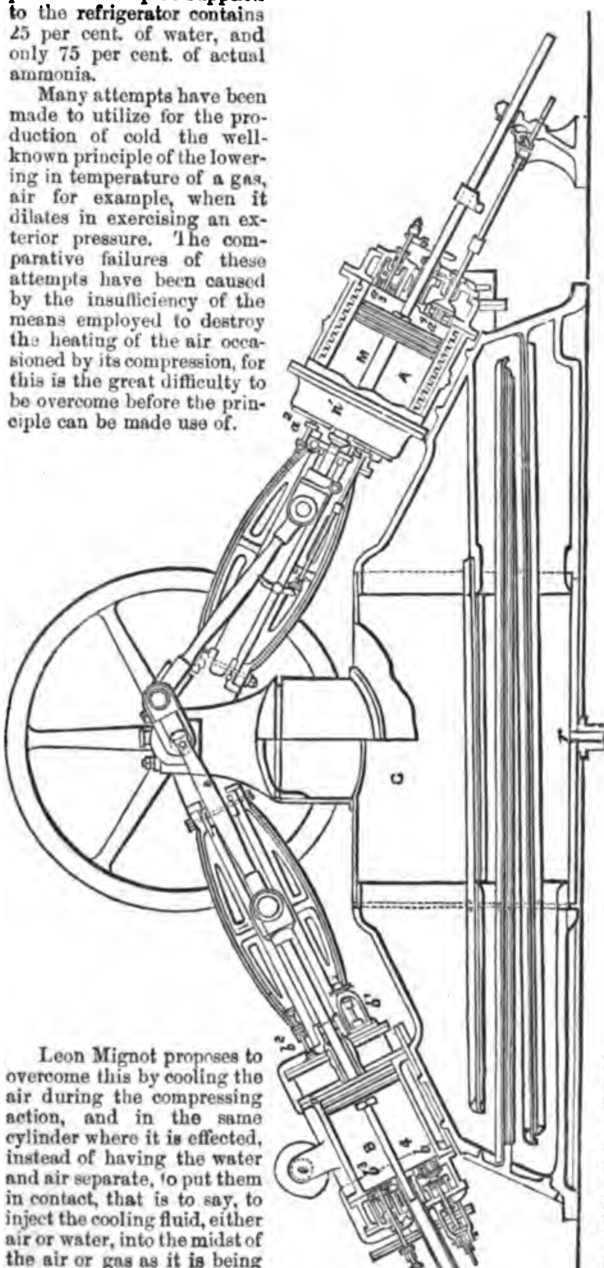

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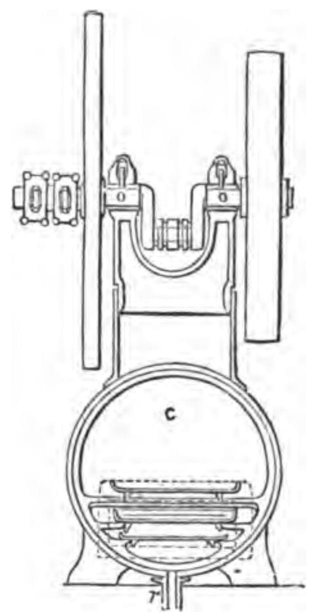

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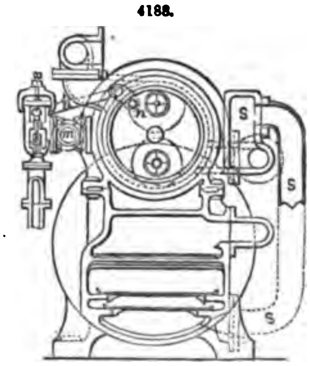
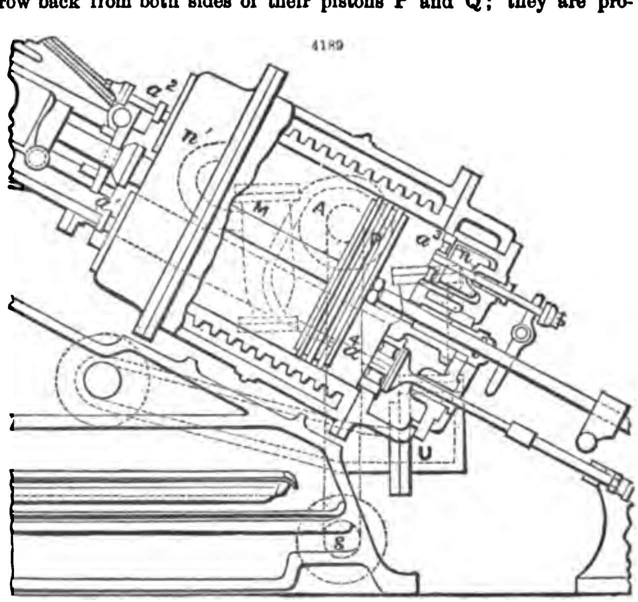


Leon Mignot proposes to overcome this by cooling the air during the compressing action, and in the same cylinder where it is effected, instead of having the water and air separate, to put them in contact, that is to say, to inject the cooling fluid, either air or water, into the midst of the air or gas as it is being compressed.

Fig. 4186 of the accompanying drawings is a longitudinal section of Mignot's ice-making machine; Figs. 4187, 4188, transverse sections; and Fig. 4189 an enlarged section of the compression cylinder A.

The air receptacle G forms the base of the whole machine; it supports at its ends the compression cylinder A, and the expansion cylinder B, and at the centre the supports of the crank-shaft O, the centre por-

tion of which receives the rods of both cylinders. Each of the cylinders is double-acting, that is to say, they aspire and throw back from both sides of their pistons P and Q; they are provided with valves a^1, a^2, a^3, a^4, serving for the suitable distribution of air for the compression cylinder A, and b^1, b^2, b^3, b^4, for the expansion cylinder B. The valves are formed of metal discs provided with a copper ring, cut in such a manner as to close the orifice, following a circumferential line of contact. The valves are worked by rods actuated by forked arms, commanded in the case of the compression cylinder by butting-pieces fixed to the piston-rod, and in the case of the expansion cylinder by eccentrics fastened on the main shaft. The compression cylinder A draws the air through its two aspiration valves a^1, a^2, and throws it out through its two other valves a^3, a^4; against this cylinder the injection arrangement is fitted for the cooling of the air in proportion to its compression. It is simply composed of a pump M, the piston m of which, actuated by a rod united to the principal crank, sends the cold water through one of two pipes n and n^1 into the part of the cylinder where the compression takes place. The mixture of compressed air and water without being heated proceeds by one of the outlet-valves a^3 or a^4, and enters into the receptacle S, which forming a siphon serves to effect the separation of the fluids through the water falling to the bottom. The air being retained at the upper part of the receptacle is allowed to escape through a valve or port and pipe, which leads it to the lower part of the receiver G. The water on the other hand descends into a reservoir U, where it finds its level; the excess falls into the air receiver through an orifice situated at its side. The receiver is provided with inclined plates forming a zigzag course or passage, in which the two fluids, air and water, circulate in a contrary direction; the air rising to the upper part of the chamber and kept in reserve to be taken by a pipe which leads it to the expansion cylinder B, whilst the water which has passed through the pipe in U flows downwards towards r, and leaves the receiver finally, or is again returned to the apparatus by an injection-pump. The expansion cylinder B draws the air from the receiver G through the pipe communicating with the two outlet-valves b^1, b^4. The refrigerated air leaves the cylinder through one of the outlet-valves b^2, b^3, and passes into a pipe e, from whence it is led into the medium or place to be cooled or frozen.



With this arrangement of mechanism the lowering of the temperature may be carried to any desired extent by taking a portion of the cold air produced in order to cool the injection-water, or even by directly compressing this cold air in the compressing cylinder A.

It will be seen that in consequence of the inclination of the two cylinders A, B, and of the junction of the cranks of their respective pistons P and Q upon the same shaft O, the compression and expansion take place simultaneously, the second action aids the first which gives the resisting force and develops the frigorific disposition already attained.

This article is taken, with some addition, from an excellent paper in the Quarterly Journal of Science, on the Artificial Production of Cold, by Dr. B. H. Paul.

IMPACT. Fr., *Choc*; Ger., *Stoss, Urto*; Span., *Empaquetár*.

The word impact implies contact or impression by touch; collision; force communicated. More particularly impact is the single instantaneous blow or stroke of a body in motion against another either in motion or at rest.

IMPETUS. Fr., *Mouvement*; Ger., *Grösse Bewegung*; Ital., *Energia dinamica*; Span., *Impetu*.

Impetus is the force with which any body is driven or impelled; or its momentum.

INCLINED PLANE. Fr., *Plan incliné*; Ger., *Schieft Ebene*; Ital., *Piano inclinato*.

See Mechanical Powers.

INCRUSTATION OF BOILERS. Fr., *Incrustation des chaudières à vapeur*; Ger., *Kesselsteinbildurg*; Ital., *Incrostazione delle caldaie*.

Undistilled water generally contains in solution a quantity of sulphate of lime, gypsum, and limestone, chalk, as well as smaller quantities of other substances. Certain waters also contain acid particles which destroy very rapidly metallic vessels used for evaporation.

If water is evaporated in a boiler, the solid substances which the water contains in solution are not evaporated with it, and it will be found that the water becomes more and more saturated as the calcareous salts are deposited upon the metallic walls. If these deposits are not removed they will finally become solidified and form upon the walls of the boiler a crust, the thickness as well

as the hardness of which increases as frequently as the water is renewed, and it then becomes necessary to use for its removal scaling hammers and chisels. A steam-boiler covered on its interior with a crust of solid deposits termed scale, has its evaporating power diminished by the reduced inductibility of the plates, and is exposed to the greatest dangers of explosion. In fact, any plate covered on the interior side with a substance which arrests the prompt transmission of heat, may be heated on the exterior side to a red heat, which will necessarily diminish the resistance of the metal by increasing the oxidation, thus reducing rapidly the thickness of the plate.

The disadvantageous consequences will be increased as the interior space of the boiler is diminished, so that in boilers with tubes, the scale may often be accumulated to such an extent that the space between the tubes may be entirely filled. If it now happens that the water finds its way through cracks in the scale between the latter and the decayed and almost red-hot plate, a sudden formation of steam takes place, which detaches the scale over an extended length, exposes a great part of the red-hot plate to a much higher temperature than that of the evaporation, and finally brings the water of the boiler in contact with the superheated plates; the consequence is the sudden production of a great volume of steam, causing almost inevitably an explosion.

Admitting that this extreme case does not very frequently happen, the accumulations of solid deposits and of a great thickness must, nevertheless, eventually bring about the destruction of the boiler, and will in all cases reduce its steam-raising power. It is therefore of the greatest importance to prevent the incrustation of a boiler by arresting solidification of the deposits, if that is possible, or at least by cleaning the boiler before the scale has attained a certain thickness.

The means employed for preventing incrustation are;—

Frequent extraction before solidification, and repeated cleanings;

The addition of substances capable of preventing the adhesion to the plates;

The addition of substances which form a chemical combination with the calcareous salts and modify their properties; and

Feeding with water previously purified.

Mechanical extraction of the deposits and frequent cleaning of a boiler are the means most generally adopted, independently of the nature of the deposits, for preventing incrustation. The operations should be repeated as often as required by the calcareous composition of the water used for feeding the boiler.

The extraction of the deposits, at least of the liquid portion of them, may be effected by means of special tubes designed for the purpose; the solid scale fixed to the plates of the boiler or heating tubes, especially at the places exposed to great heat, can only be removed by striking them with a scaling hammer after the boiler has been emptied. If moderately pure water is used for the boiler, extraction and cleaning are sufficient, but the cleaning should be repeated frequently, so that the deposits are not allowed to get hard; should, however, a few solid deposits remain behind, the hammer has then to be used, and with this view, the diameter of the boiler should be arranged so as to allow admittance of a man or boy.

Care should, however, be taken to empty the boiler only when cold, otherwise the furnace of the boiler, still very hot, calcines the residue after the water has been let off, and it becomes then very difficult to remove.

It is therefore indispensable that no part of a boiler should be inaccessible to necessary tools for separating and removing the deposits; it is of equal importance that the parts in direct contact with the hearth should present no marked projection or deepening in which the calcareous products could accumulate, get hard, and become almost immediately separated from the liquid. Such is especially the case in the joints of the fire-box of locomotives and in other steam generators of a similar construction, where care is taken to fix plugs which may be removed when desired in order to introduce tools through the holes for the raising of the deposits.

Substances hindering the adhesion of Deposits.—If the water used contains a high percentage of calcareous salts, and if frequent cleaning of the boiler does not prevent the formation of scale, it becomes necessary to adopt special means to diminish the inconvenience.

The following remedies have, among others, been used with varying success to prevent incrustation;—

1. Potatoes, $\frac{1}{50}$th of weight of water prevents adherence of scale.
2. 12 parts salt, 2½ caustic soda, ¼th extract of oak bark, ½ potash.
3. Pieces of oak-wood suspended in boiler and renewed monthly.
4. 2 oz. muriate of ammonia in boiler twice a week.
5. A coating 3 parts of black-lead, 18 tallow, applied hot to the inside of the boiler every few weeks.
6. 12½ lbs. of molasses fed into an 8-horse boiler at intervals, prevented incrustation for six months.
7. Mahogany or oak saw-dust in small quantities. Use this with caution, as the tannic acid attracts iron.
8. Carbonate of soda.
9. Slippery elm-bark.
10. Chloride of tin.
11. Spent tanners' bark.
12. Frequent blowing off.

Preliminary Purification of the Feed-water.—There is no better means of preventing incrustation than to feed the boiler, where circumstances permit, with water already purified and free from all calcareous salts or corrosive acids.

There are two ways of obtaining this result; preliminary distillation, and chemical operation.

If the water destined for the feeding of a boiler had to be always distilled, the expenses for

fuel would be doubled; this plan has therefore to be abandoned, unless the waste heat of the boiler-furnace can be utilized for the purpose.

This has been tried in many cases; the first or preliminary heating of the water being effected in auxiliary recipients or vessels of less importance than the boiler, and which are not exposed directly to the fire upon the grate. The incrustation in these vessels will therefore be less strong than in the boiler.

The importance of the deposits could also be much diminished by the condensation of the steam used in the engine, upon cold surfaces in order to make it again applicable for the feeding of the boiler by adding only the small quantity of water necessary to make up for evaporation which had been condensated in reservoirs plunged into the sea outside the ship; this plan was tried and at first succeeded; it happened, however, that these reservoirs became covered on their outside with a deposit of scale from the salt water, in consequence of which their conductibility was much reduced.

In France M. Lelong-Burnet has introduced a method of purifying feed-water, which consists of a preliminary mixing of the water with chemical agents producing a precipitation of all the substances forming incrustation, so that only pure water reaches the boiler. He employs for that purpose special reservoirs provided with stirring apparatus in order to effect the mashing of the chemicals cast into the water in suitable proportions; the existing salts are thus dissolved and others formed which precipitate to the bottom of the vessels.

It will be seen that the application of the process makes a previous careful analysis of the feed-water indispensable, in order to select, according to its composition, the reacting agents which are best for the complete precipitation of the salts in solution. Burnet has made for that reason a great number of experiments in order to ascertain the most suitable agents for attaining the desired end, and to find the proportions which have to be used according to the nature of the feed-water. He has proposed for the purpose a great number of agents, and especially the solutions of caustic potash and soda, those of alkaline carbonates, baryta, strontianite, and so on. See Corrosion.

INDIA-RUBBER. Fr., *Caoutchouc;* Ger., *Kautschuk;* Ital., *Gomma elastica caciù;* Span., *Cautchuc.*

India-rubber, known generally as caoutchouc, is composed of carbon and hydrogen, eight equivalents of the former uniting with seven of the latter. This compound is represented by the formula $C_8 H_7$. When perfectly pure, it is solid, white, and transparent. Its specific weight is 925, that of water being 1000. At a temperature varying from 75° Fahr. to 95°, it is supple and elastic; and its surfaces, if free from all foreign matter, or recently cut, adhere and become united when placed in contact under a certain pressure. The physical properties of caoutchouc are greatly modified when its temperature is brought below 32°; it then undergoes a considerable contraction, it becomes less supple, only slightly adhesive, and hardly susceptible of extension. These changes of properties remain even after the temperature has been raised again to 60° or 70°. If a piece of caoutchouc be stretched and cooled down to 32°, it will remain in its extended state, even after its temperature has been raised again to 70°. Its primitive characteristic qualities suddenly return, however, when its temperature is raised above 95°. To make the experiment, take a strip of caoutchouc, stretch it, and place it for a few minutes in water at 32°; on taking it out of the water it will remain in its extended state and possess but very little elasticity at ordinary temperatures. But if it be plunged in water at 105° or above, it will immediately resume its original dimensions and all its elasticity. A strip of caoutchouc suddenly stretched manifests a sensible increase of temperature if placed in immediate contact with the lips. Sudden contraction, on the contrary, causes a diminution of temperature. The reason of this is that in the former case the stretching lessens the volume of the strip, whilst in the latter the volume is increased by the strip returning to its primitive dimensions.

Several liquid carburets of hydrogen, obtained from coal-tar by distillation—particularly benzine—expand and partly dissolve caoutchouc; the same effects are produced by essence of turpentine, deprived of water by quick-lime, and rectified by distillation. Pure essence of lavender and sulphuret of carbon are still more effective. The fat oils may dissolve a small quantity of it, especially when hot. Water and alcohol, which were believed formerly to have no effect upon it, exert a special action and precipitate it in part from its solution in sulphuret of carbon.

Liquid and gaseous chlorine hardly affect caoutchouc, and it is equally insensible to the action of hydrochloric acid, all the weak acids, the greater part of the gases, and the solutions of potash and soda. The concentrated sulphuric and nitric acids change it rapidly, especially when they are mixed, $SO_3, HO + NO_5, HO$.

The effect of steam upon caoutchouc is to soften it and greatly diminish its tenacity. When heated dry from 95° to 250°, it gradually loses its consistency; its particles become more and more susceptible of agglutinating together. At a temperature of about 290° to 330°, it is viscous and adheres to hard and dry substances; a large portion, however, of its consistency and elasticity is regained after cooling. From about 355° to 390° it fuses and appears to undergo an isomeric modification; for while its elementary composition remains unchanged, it has become sticky; if heated still more, up to 430° to 450°, it becomes oily, very brown, and suitable for protecting iron and steel from rust.

Caoutchouc, in contact with a substance in a state of ignition, burns with a luminous red and smoky flame. When subjected to distillation, it gives different carburets of hydrogen, two of which are isomeric with olefiant gas (caoutchene, hevëene); several others have an elementary composition, similar to that of essence of turpentine; they boil at various degrees—57°, 91°, 340°, 419°; most of them dissolve small pieces of dry caoutchouc.

The caoutchouc of commerce is composed of two principal parts, one possessing greater cohesion among its molecules, and being more tenacious and capable of resisting all agents; the other softer, ductile, adhesive, and more soluble. Each of these two parts offers the same elementary

composition represented by the formula C_8H_7; the mass thus constituted contains fatty matters, an essential oil, coloured matters, three nitrous substances, water in variable proportions, which may be as great as 26 per cent., and traces of saline matters.

No one of these substances possesses the extensible and elastic properties in the same degree as the whole together; this seems to be due to the adhesion between the surfaces of the fibrous parts which are lubricated by the fatty matters, and to the isolation of the soft and soluble portion, which would render the whole mass more supple. The structure and composition of caoutchouc enable us to explain several phenomena concerning the penetration of sulphur, the vulcanizing of caoutchouc, and the slow or rapid changes in vulcanized caoutchouc.

In course of time, especially when exposed to the light and to a high temperature, caoutchouc undergoes changes, the effects of which may be seen, though their consequences on the immediate composition of the substance have not yet been determined; in such cases it exhales a sharp odour, it becomes softer and less tough, and sometimes even it may be easily broken.

Caoutchouc and some of its ruder uses were known long ago in South America and in India. In 1736, La Condamine, of the Institute of France, who had been sent to Peru with Bouguer for the purpose of making certain astronomical studies, sent the first specimen of this substance to the Academy of Science of the Institute. Fresnau and Macquer in 1751 and 1768 sent to the Academy some specimens of caoutchouc grown at Cayenne. It was not till the end of the last century that caoutchouc was first imported into England, where it became known under the name of india-rubber, from the almost sole use to which it was for a long time put of rubbing out lead-pencil marks.

In 1790, the raw material cut up into strips began to be used to make elastic balls, ligatures, and certain kinds of springs. Later methods of softening caoutchouc and spreading it over coarse fabrics to render them waterproof were discovered. Fourcroy succeeded in causing it to swell and partially dissolve by means of ether. Grassart in 1791 first made tubes of caoutchouc by winding long strips of that material helically upon slightly conical glass moulds, and joining the whole together. Nadler in 1820 invented a method of cutting caoutchouc into threads suitable for weaving into elastic tissues, and about this time Thomas Hancock introduced the use of the devil or masticator into the manufacture of caoutchouc. This machine, together with his after inventions, were the principal means of extending the india-rubber trade to the dimensions it has now attained.

A few years later, Mackintosh improved the manufacture of single and double waterproof fabrics by interposing a layer of caoutchouc rendered plastic by means of essence of turpentine; he gave a great impulse to the manufacture of overcoats of this material, which overcoats still bear his name. Towards the year 1830, Rattier and Guibal wove fabrics of caoutchouc threads deprived of their elasticity by means of a low temperature; by afterwards heating these fabrics up to about 105°, elasticity was restored to the threads. This method is still employed.

Hayward's patent, taken out on the 24th of February, 1839, by Goodyear, his representative, marks the first use of a small quantity of sulphur; but he did not state either the proportion or the temperature requisite for the transformation. In 1844, Goodyear described the properties—partly discovered in 1839—which sulphur gives to caoutchouc by uniting with it; from this time the operation was known as *vulcanizing*. The same year, Hancock succeeded in vulcanizing caoutchouc by means of a bath of sulphur.

The preparation and vulcanizing of caoutchouc were further improved by Rattier and Guibal. Parkes in 1846 invented the method of vulcanizing by immersing the manufactured articles in sulphuret of carbon containing $\frac{1}{40}$ (or $2\frac{1}{2}$ per cent.) of protochloride of sulphur. Several manufacturers applied this method in various ways, and produced a great number of useful articles. M. Guibal, out of a mixture of caoutchouc and silicate of magnesia, formed cylinders, from which thick washers are cut to be used between the stuffing in stuffing boxes. Recently M. Gérard has constructed an ingenious machine capable of cutting 150 prismatic threads at once instead of eight or ten as formerly.

We will now describe the chief processes employed in manufacturing various articles of caoutchouc. When the methods of extracting the raw material in the countries where it is grown shall have been improved, we shall no doubt be able to obtain directly thick and homogeneous squares and cylinders free from foreign matter. It will then be easy to cut up, by means of machinery, these raw products into thin strips and fine threads, from which a great number of articles may be made much more durable than those prepared by working up the caoutchouc, because in that case the natural texture would not be injuriously changed by exposure to a high temperature.

Threads of pure Caoutchouc.—The irregular bottles of the raw caoutchouc of Para, softened in hot water and then cut in two and flattened between cast-iron plates heated up to 212°, are cut up by a circular knife worked by machinery into discs; these discs are fixed upon an axis, which as it revolves presents the disc to the edge of a circular knife. By this means it is cut up spirally into a long strip of any required thickness, and wound upon a reel. A small jet of water assists the action of the knife. A simple mechanical contrivance controls the action of this circular knife by displacing the centre of rotation and accelerating the motion as the circumference of the disc diminishes. The strip is afterwards subdivided simultaneously into five or six threads by being passed between from six to twelve double circular blades cutting in the manner of shears. This action is likewise assisted by the continuous flow of a small jet of cold water. A boy on the other side gently pulls the threads towards him, and thus assists the passage of the strip.

The thread obtained by this process is, in general, the most elastic and durable that can be obtained. It is first stretched, and its elasticity removed by means of a reduced temperature, in order that it may be more easily woven; contraction and elasticity are afterwards restored to the threads of the finished fabric by heating it in a stove up to 112°. These threads of pure caoutchouc possess the defect of becoming hard when exposed to cold and soft when exposed to heat, and for this reason vulcanized caoutchouc is generally preferred.

Various Operations performed on the Raw Material.—One of the first operations which caoutchouc is made to undergo consists in steeping it twelve to twenty-four hours in warm water; then, after

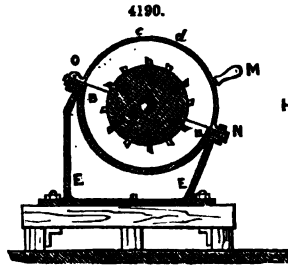
having cut it up into pieces of about an inch thick with a long sharp knife, these irregular pieces are passed successively between two large rollers of about 15 in. in diameter moving at different rates of speed, one making one revolution and the other two-thirds of a revolution a minute, while a jet of water falls continuously upon the upper roller. In this way the pieces of caoutchouc are crushed, rolled, and at the same time pressed out unequally in the two directions; they issue as thin, granulated strips, full of little holes, thus presenting a large surface to the action of the weak solutions of soda and the hot water by which they are purified and rinced, the air which dries, and the various mechanical and chemical agents which agglomerate, distend, or dissolve them; such, for example, as the deviling machine, hydrocarburets and sulphuret of carbon, the application of which we will describe later. The bottles or hollow cones of raw caoutchouc are left to soak in the warm water for three hours, and then taken out and cut asunder by means of a circular knife which is kept constantly watered. This watering is necessary whenever caoutchouc has to be cut, to counteract the adhesive property of the material and prevent an increase of temperature which would result from the friction, and which would increase the tendency of the caoutchouc to stick to the knife. The bottles when thus cut open let out into the water, into which they are again plunged, the earthy matters they may have contained.

For the raw caoutchouc of Brazil, which is less impure than the other kinds, cleansing by water alone is usually sufficient; it is then passed between the toothed cylinders, which reduce it to thin sheets full of holes.

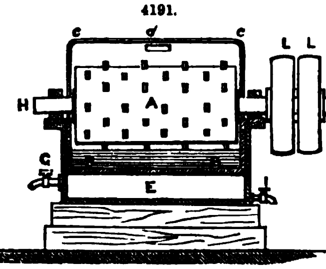
The *agglomeration* of the caoutchouc, introduced by Hancock, is an operation forming the basis of a great number of the preparations which we shall presently describe, and is effected in the following manner;—

The thin strips, obtained by the rolling already described, having been well washed and dried in the air, are made up into a packet or bundle weighing 14 kilogrammes or about 30 lbs., including the scraps and other work from the preceding operations, and heated in a stove up to about 95°. This bundle is then passed between a massive iron cylinder A, Figs. 4190, 4191, 17 centimètres in diameter, and armed with iron pins or teeth 5 millimètres square, let 4 centimètres into the cylinder and projecting 2 centimètres above its surface, and the iron cylindrical casing, one portion B B of which is fixed and the other portion C is removable. The bundle of 14 kilogrammes is compressed and rolled out between the toothed roller, which makes from 60 to 100 revolutions a minute, and

4190.



4191.



the outer casing B and C which is provided with several projecting diamond-points. The parts of the bundle become heated successively, and, joining together, they at length form a flat lump. This lump, dragged slowly by the powerful friction of the teeth, makes one revolution while the cylinder makes 30 or 40.

To give an idea of this trituration, we may state that it requires a force of 5 horse-power, and that the bundle of caoutchouc, condensed by the close adhesion of the fragments of which it is composed, possesses at the expiration of ten minutes, the time required for the operation, a diameter of 18 or 20 centimètres and a length of 40 centimètres. Such are its dimensions at the moment when it was taken out of the *devil*, in which its form was quite different, as it was compressed between surfaces only 6 centimètres apart, and limited by the two ends of the cylindrical chamber only 35 centimètres distant from each other.

In winter, during the first quarter of an hour, the agglomeration of the caoutchouc is assisted by heating the cylindrical chamber up to 112° by injecting steam into the double bottom E, Figs. 4190, 4191, by means of a cock G. A rectangular aperture *d*, or several long and narrow apertures, allows the bundle or lump of caoutchouc to be seen and touched. When the operation is completed, the cover is taken off by removing the pin N and raising the handle M. The roll is then taken out, and replaced by another of 14 kilogrammes prepared in the same manner.

As the rolls sometimes acquire a high temperature in consequence of the great friction to which they have been subjected, which temperature would be retained in the middle of the lump for a long time by reason of the low conductivity of the substance, it is necessary, to prevent injury to the material, to cut them asunder through their axis. This is done with a kind of hand-saw without teeth. The heating becomes of more importance in machines of larger dimensions, giving rolls weighing from 28 to 30 kilogrammes; it may be partially avoided and the introduction of the air into the caoutchouc prevented by substituting for the iron pins rounded flutings, projecting 4 centimètres and having a breadth of 4 centimètres at their base.

When it is required to make these rolls up into blocks, they are placed in the stove and heated up to 112° throughout their mass; they are then rolled out into thick sheets between hollow cylinders heated internally up to 105° by steam, and fixed 3 or 4 centimètres apart. Six or eight of these sheets or tablets are then placed one upon another and put under a hydraulic press, where they are left to remain subjected to a great pressure for about a week. The pieces become joined together, and on cooling retain the form they have assumed, of a rectangular prismatic block. This block is kept in a cellar as long as possible, or stored away for several months.

To cut up one of these blocks, it is fixed with india-rubber paste upon the travelling plate or carrier of a machine-knife fixed like a saw for cutting veneer. The carrier is moved forward by

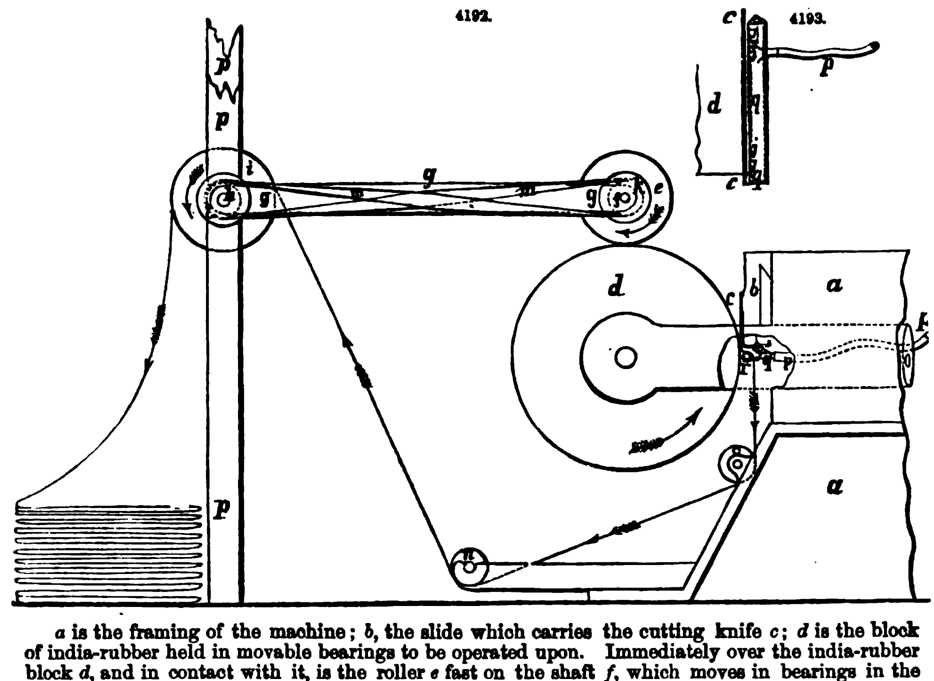
means of a long screw, and the piece of caoutchouc is thus kept up to the edge of a very sharp horizontal knife in rapid reciprocating motion (600 to 800 strokes a minute). To destroy the elasticity and prevent the heating and consequent adhesion of the caoutchouc, a jet of cold water is made to play continuously upon the edge of the knife. When the block has been cut through, it is drawn back, raised by means of screws beneath the support $\frac{1}{2}$, $\frac{1}{4}$, or several millimètres, according to the thickness required, and again pushed forward as before. The sheets thus obtained are used to make tubes, bracelets, garters, balls, and various surgical utensils; all these articles, after they are made, should be sulphuretted to render their elasticity stable.

For cutting the blocks into sheets Charles Moseley invented a machine which, among other improvements, has a drawing or taking-up motion for keeping the sheet of india-rubber at one even tension, and so producing a greater uniformity of thickness and smoothness of surface.

The motion consists of two levers fixed upon the centres of two rollers. One of these rollers revolves in a fixed bearing, and the other roller rests upon the block of india-rubber to be cut into sheets; this roller rises or falls according to the diameter of the block. As the block revolves it comes in contact with the cutting knife, which by an oscillating motion cuts from it a sheet which passes over guide-rollers. As the block revolves it gives a motion to the roller bearing on it, which by means of straps and pulleys gives a rotatory motion to the roller, over which passes the sheet of india-rubber, and as the roller bearing on the block of india-rubber has a surface speed corresponding to that of the block, which decreases as the block decreases in diameter, the sheet of india-rubber is kept at one exact tension. The same effect may also be produced by self-acting cone-pulleys, to give a positive motion to the drawing roller corresponding to the decreasing surface speed of the block. It is necessary in cutting india-rubber to have a stream of water running upon the face of the knife to reduce friction; but to produce a smooth surface upon both sides of the sheet Moseley applies a stream of water to the back of the knife in addition to that at the front.

Fig. 4192 is an end view of Moseley's machine, and Fig. 4193 a plan of the arrangement for watering the back of the cutter.

4192.



4193.

a is the framing of the machine; *b*, the slide which carries the cutting knife *c*; *d* is the block of india-rubber held in movable bearings to be operated upon. Immediately over the india-rubber block *d*, and in contact with it, is the roller *e* fast on the shaft *f*, which moves in bearings in the two levers *g*, one of which is at each end of the roller *e*. The fulcrum of the levers *g*, and on which they are free to move, is the shaft *h*, which is the axis of the drawing or taking-up roller *i*; this roller *i* is covered with india-rubber, and revolves in fixed bearings in the upright standards *p*. On the shaft *h*, and also on the shaft *f*, which is the axis of the roller *e*, are keyed the two pulleys *k* and *l*, the crossed strap *m* being passed around them. Similar pulleys *k* and *l* and crossed strap *m* are made use of on the opposite ends of the shafts *h* and *f*, and three guide-rollers *n*, *o*, and *r*, are mounted in bearings fixed to the frame sides *a*. The apparatus for supplying water to the back of the cutting knife consists of a tin or light metal trough *q*, V-shaped or otherwise, which extends across the machine the length of the cutting knife. The trough *q* is closed all round, except on the inside edge or lip which is next the cutting knife, where suitable openings *j*, Fig. 4193, are left for the egress of the water, which is supplied to the trough *q* by means of a flexible pipe *p* of india-rubber connected by a branch to the pipe for supplying water to the front of the cutting knife, or from other suitable source at the back of the machine. The trough *q* is fixed under the slide *b* which carries the cutting knife *c* by a thin metal flange fast to and projecting from the trough *q*, and bolted in between the face of the slide *b* and the cutting knife *c*, and it is thus carried

backwards and forwards with them, the flexible pipe *p* being made sufficiently long for that purpose; this motion assists in the distribution of the water along the block of india-rubber *d* from which the sheets are cut.

The mode of operation is as follows;—The attendant having put the machine in motion and turned on the supply of water, the sheet of india-rubber as it is produced by the action of the cutting knife is, as indicated by the arrows, passed over the guide-roller *r*, under the guide-rollers *o* and *n*, and over the drawing or taking-up roller *i*, which revolving and being covered with india-rubber has sufficient bite or hold on the sheet to draw it forward with the required tension. The speed of the roller *i* is required to decrease with the size of the block of india-rubber *d* under operation, for as the sheet is cut from it less length is produced during each revolution of the block *d*, and as it decreases in circumference, its rotatory speed being the same, the roller *e* in contact with it will be driven slower, and will communicate its decreasing velocity by means of the crossed straps *m* to the taking-up roller *i*, so that the sheet of india-rubber will be taken up as it is produced and deposited in folds in front of the machine.

Guibal easily obtains solid cylinders of caoutchouc by placing in a cast-iron mould one of the rolls as soon as it comes from the *devil*. The roll being placed vertically in the mould, an iron piston or ram is put upon it, and then placed under a hydraulic press. When the maximum pressure has caused the roll to assume the cylindrical form, the ram is fixed in this position for twenty-four hours, or even longer, to allow the caoutchouc time to cool and set.

These cylinders are afterwards cut up into sheets by means of the knife described above; but in this case, the section having to be made according to a spiral, the cylinder must be made to revolve, not by the uniform motion of its axis, but according to a uniform velocity of the sheet taken off by the knife. M. Guibal has solved this difficult problem by a very simple and remarkable contrivance. The rotary motion is communicated to the cylinder of caoutchouc by means of an endless strip of linen cloth, which, guided by rollers and always possessing the same velocity, since its length does not vary, allows each oscillation of the knife to advance by an equal quantity; it follows from this that the streaks or cuts slightly marked by each oscillation are equidistant, like those which are obtained by moving forward with a uniform motion the rectangular blocks placed horizontally upon the machine table.

Tubes and other hollow articles of all forms may be easily made of these flat pieces of caoutchouc by cutting the edges short off and bringing the sections in contact under pressure and welding them with a hammer upon an anvil. The operation must be performed in a warm place (about 75°), and the caoutchouc must be of the same temperature. If it has been previously cooled down to 32°, it must be reheated up to 105° to restore its elasticity and adhesive quality. The articles may be vulcanized cold after they are made, by a process which we shall presently describe.

Recently a new kind of rolling machine has been substituted for the *devil*, already shown in Figs. 4190, 4191. It consists of two hollow cast-iron cylinders, 33 centimètres in diameter and 75 in length, heated internally by steam; one of the cylinders is grooved longitudinally, and revolves with a greater velocity than the other in the ratio of 3 to 2, the motion being transmitted from one spindle to the other by means of toothed wheels of different diameters. The axes of both cylinders are in the same vertical plane, about 20 kilogrammes of caoutchouc in flat pieces is introduced between them, and as the machine is not covered in, the work can be easily watched. Moreover, as the roll of caoutchouc produced is not very thick, there is nothing to fear from an accumulation of heat in the middle of the mass.

Threads of caoutchouc are obtained by cutting up a piece of agglomerated caoutchouc 2 or 3 centimètres thick with a punch, or by means of the circular knife, into discs of 15 or 20 centimètres in diameter; these discs are then cut up spirally into strips, which are then subdivided into threads in the way described under the head of natural caoutchouc. The discs to be cut up into strips may be prepared in two other ways, by cutting them from the cylindrical blocks obtained by moulding the lumps taken from the deviling machine, or from cylinders prepared by rolling up a sheet of caoutchouc that has been worked and rolled between hot cylinders.

A great improvement has lately been made in the fabrication of *square* shreds in the form of a machine invented by M. Gérard. To produce threads by this machine, a thin piece of Para caoutchouc worked up with six hundredths of sulphur, and rolled out between hot rollers, is sprinkled, as it comes from the cylinders, with talc on both its surfaces. This sheet is then wound with a piece of linen cloth interposed upon a hollow mandrel, or kind of plate-iron bobbin. Its breadth is about 66 centimètres, its length 60 mètres, and its thickness varies from half a millimètre to 1, 2, or 3 millimètres, corresponding to threads whose section is a square having sides of one of these four dimensions. All the sheets thus rolled up are placed, by means of a rod passing through the hollow axis of the bobbins, into a stout vertical plate-iron cylinder, where they are exposed for two hours to a temperature of 285°, produced by steam injected under a pressure of four atmospheres into the closed cylinder. The long sheet of caoutchouc is then ready to be cut up in three cuttings throughout its whole length, a little margin being left at the edges to allow for any irregularities in the width.

The principal part of the ingenious machine producing this result, is composed of from 150 to 250 circular blades 7 centimètres in diameter and one-tenth of a millimètre thick, punched out of thin watch-spring steel. These blades or knives are kept at an equal distance from each other by brass washers from one-half a millimètre to 1, 2, or 3 millimètres thick, and 6 centimètres in diameter, all firmly held together by a nut on the end of a stout spindle. Beneath is a solid half-hardened india-rubber cylinder fixed upon a spindle parallel to the former, and in the same vertical plane. This cylinder, into which the knives slightly enter, supports the threads as they pass and are cut. The sheet of caoutchouc, moistened with water, is then placed between the knives, which are raised for a moment in order to mark a marginal border in front, and the rapid motion of 1500 revolutions a minute communicated to the spindle, whilst the solid india-rubber cylinder makes only 8 or 10. A continuous flow of small jets of water prevents adhesion and

friction, and a kind of brass comb separates the threads. So fine are the sections, that the sheet of caoutchouc issues from between the knives without any apparent division having been made; but the lightest touch shows the 150 to 250 threads. These threads are tied up into skeins and cleansed, first in a solution of potash heated up to 212°, which softens the surface, and then in pure water. When they have been dried in the air, they are passed over a table between vertical round brass teeth, to destroy any slight adhesion; they are then ready for weaving. This machine makes in a given time as many threads as ten or fifteen common machines.

Solid balls of caoutchouc are made by placing the end of a roll against a revolving cylindrical rasp, formed of a sheet of iron punched full of small holes and having the burr on the outside, like a sugar-rasp. The great friction caused by the rapid motion of the rasp, 500 to 600 revolutions a minute, soon divides the mass of caoutchouc up into small fragments, which, having become heated by the friction, have acquired so adhesive a property that they form only a soft and pulpy mass. While in this state, it is made into an irregular ball by hand and placed in a cast-iron mould having two turned and polished hemispherical cavities; these two halves may be powerfully pressed together by means of a hoop and screw. A small quantity of the soft material is pressed out of the joint and forms a ridge; this is removed by changing the position of the ball in the mould. The pressure is then increased, and the ball left to cool; in twelve hours the ball will become very hard, and may be taken out of the mould. To restore its elasticity, it is kept for half an hour in a stove or in water heated to 122°, and then left to cool in an ordinary temperature.

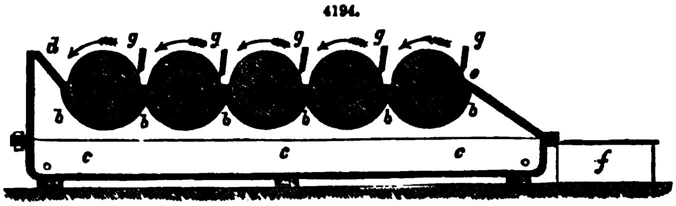
Thin filaments of caoutchouc are prepared by a kind of rolling when hot. A roll is taken as it comes from the deviling machine and flattened by pressure or cut in two longitudinally by a plane passing through its axis. The part thus obtained is heated in a stove up to 100° or 120°, and then passed several times between the cylinders of a rolling machine. These cylinders, which are hollow, are very gradually brought together during the process of rolling, and their temperature is raised to about 175° by putting red-hot bars of iron inside, or better, by an injection of steam. When the thickness of the caoutchouc is reduced to 2 or 3 centimètres, it may be folded double and passed through again several times in this way to render the substance homogeneous. The binding screws of each of the bearing blocks of the upper cylinder are then tightened and the sheet of soft caoutchouc again passed through; on leaving the rollers this time it is very thin. It may be obtained of any length as, to continue it, it is only necessary to supply the machine with material.

This thin filament is soft and very sticky; in this state it is put between two tissues and the three thicknesses passed between the rollers of a second machine. In this way stout waterproof fabrics are made, rather heavy, perhaps, but free from the strong smell of common *dissolvents*, as these are altogether excluded from the preparation. When it is required to leave one face of the caoutchouc bare, one tissue only is used. The edges of this double tissue, folded in two and cut up into circular elliptical and rectangular forms, may be made to adhere at pleasure. The edges of the caoutchouc, put in contact and pressed hot, join and form a closed vase. A space is left in one of the corners for an ajutage, which is stuck in with caoutchouc paste. This ajutage, which is provided with a small screw stopper, is used to introduce into the vase or bag the solution for vulcanizing the caoutchouc and afterwards the air with which this kind of bag is distended to render it *elastic*.

When it is required to obtain the filament of caoutchouc alone, it is made to pass, as it comes from the hot rollers, into a bath of cold water very slightly alcalized, whence it is wound upon a reel; powdered talc is sprinkled on both its surfaces to prevent their sticking. If the rolling be effected rather slowly, between cylinders heated internally by steam, the sheets of caoutchouc retain the thinness so acquired. These sheets may be coloured by means of opaque powders. In this way zinc-white gives a whitish tint, and vermilion a beautiful red; a yellow or orange-red may be obtained with the ochres, blue with ultramarine, and black with bone, ivory, or lamp black. It is in accordance with these principles that M. Gérard produces from a single piece a kind of rug with designs in relief and a deep embossing. A stout strip of caoutchouc worked up with sulphur and coloured powders, and forcibly compressed between two hollow cast-iron plates heated by steam, first up to 240° for one hour, then for two hours up to 285° in order to effect the vulcanization. These remarkable carpets may be two yards long by one broad, and as each of the patterns of two yards may be multiplied indefinitely, whole pieces of a hundred yards length may be manufactured for use in long galleries.

Pastes and Solutions of Caoutchouc.—The thin sheets of caoutchouc and those obtained by crushing and drying, as described above, are very suitable for making pastes and solutions. They are first cut up into small pieces, and then placed in contact with each other in a closed vessel, with one-and-a-half times, twice, or three times their weight of essence of turpentine rectified, or better still, benzine. After twenty-four or forty-eight hours, the caoutchouc is distended and softened; in this state it is passed through a fine cylinder crushing machine, Fig. 4194. Each cylinder is 12 centimètres in diameter, and 40 in length, and it revolves in a semicircular trough *b*, forming the upper portion of a box *b c*, heated more or less by steam. The compound being put into the shoot *d*, runs down between the first cylinder and its trough. When the substance arrives on the other side of the cylinder, it meets the edge of a knife or scraper *g*, tangent to the surface of the cylinder; it then falls beneath the next, and so on throughout the whole number of cylinders. At *e*, it falls upon an inclined plane, and runs thence into a vessel *f*.

4194.



In this crushing machine, the five cylinders receive, from an equal number of endless screws fixed upon one spindle, the motion of an equal velocity communicated by these screws to each toothed wheel fixed upon the axis of each cylinder.

The solution so prepared is used for various purposes; to stick together the parts of india-rubber articles, to join rectangular pieces of agglomerated caoutchouc end to end, and to overlay certain fabrics to render them waterproof. It is sometimes laid on the back of wainscoting in contact with damp walls, and it is frequently employed to give a strong and supple joint to the dry surfaces of many parts of domestic furniture and musical instruments. This caoutchouc paste also forms, by a very simple process, a supple binding for certain kinds of books, such as ledgers, &c. The books to be bound are put into a press, cut, and all the leaves at the back, which have been cut straight, are laid over with three or four layers of solution successively dried; upon the last layer is placed a piece of fine linen cloth by which the leaves are held to the covers.

Oils for lubricating Machinery.—Colza oil, containing 1½ or 2 per cent. of caoutchouc, cut into very thin strips, and dissolved by a temperature of 250° to 265° kept up for five or six hours, becomes slightly brown and viscous; in this state it is very suitable for lubricating the rubbing parts of machinery.

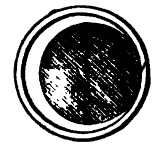
Caoutchouc Cement.—This mastic is made by melting carefully, at a temperature of about 430°, caoutchouc cut very fine. As soon as it becomes fluid, slaked lime in the form of dust or powder is mixed with it; two parts of caoutchouc and one of lime give a soft cement; by doubling the proportion of lime, we obtain a firm but supple cement. These cements remain a long time ductile and tenacious; bottles may be hermetically closed by putting some of this material round the worn edges of a stopper. If we require the outside of the cement to dry, we must employ, for two parts of caoutchouc, one of lime, and one of red-lead.

Tubing.—The paste used in making tubes may be composed of 59 parts of caoutchouc, 35 of oxide of zinc, 5 of sulphur, and 1 of pulverulent lime. The strips of caoutchouc are first sprinkled with powdered talc to prevent their sticking; to render them more homogeneous, they are usually placed for an hour upon a hollow table heated by steam up to 250°. A strip is folded double, to a breadth proportionate to the diameter of the tube, and the edges cut with shears. The incision through the two thicknesses is made at an angle of 45° with the surface of one side, and consequently of 135° with the other, Fig. 4195. When the cylindrical form is given to the piece by means of an iron rod, the two surfaces of the section fit each other, as shown in Fig. 4196, and a pressure with a bar or a few blows with a flat rule is all that is required to make the edges adhere firmly.

4195.

A

4196.



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The tubes are in this way made upon smooth iron rods from 5 to 15 millimètres in diameter and from 10 to 13 mètres in length, and sprinkled with talc. When the joint is effected, the tubes are wrapped in a cloth and vulcanized by heating them for an hour and a half or two hours to a temperature of 270° to 285°, four hundredths of sulphur having been introduced into the paste at temperatures varying from 105° to 212°. For this purpose the tubes with their rods are placed in a vertical cylinder from 12 to 13½ mètres in height and hermetically closed. Steam is then introduced, and the temperature kept at 273° by means of a gauge indicating a pressure of three atmospheres. When the tubes have cooled, the rods are withdrawn. Should the tube stick to the rod, the adhesion is destroyed by injecting water between them with a small hand-pump.

Large Sheets of Caoutchouc, Waterproof Fabrics, &c.—Processes producing large sheets of caoutchouc are employed for obtaining pure or coloured layers of that material upon silk or linen fabrics, or smooth sheets of large size, either of pure caoutchouc or mixed with colouring oxides. The process is effected in the following manner;—The caoutchouc is first dipped into hot water, cut up into shreds, crushed between rollers, washed and purified in the way we have already described. The shrivelled strips so obtained are dried for twenty-four hours in a stove, and then immersed in three times their weight of rectified essence of turpentine; in this state they are left from twenty-four to forty-eight hours in covered wooden boxes lined with plate iron, and containing 500 litres. The shreds of caoutchouc, distended by the essence, are then distributed into eight cylindrical capsules, the bottoms of which are perforated like a skimmer; the thickness of the substance in each capsule is about 6 centimètres. The eight capsules are placed in a cylindrical column closed by a cover and made to fit tight over a wide-mouthed vessel containing essence of turpentine previously rectified. The essence is then made to boil, and the rising vapour passes through the capsules, heating to nearly 322° the caoutchouc contained in them, which becomes thus more regularly and intimately penetrated with essence. The vapour of the essence escapes at the top of the column through a side pipe which takes it into a common serpentine pipe where it is condensed, giving again distilled essence fit for subsequent operations. After two hours, the capsules are taken out of the column, and their half pasty contents poured into the barrel of a vermicelli press, provided with several graduated wire-gauze screens, supported on plates pierced with holes. The pressure exerted upon the piston by means of an iron screw, forces the caoutchouc pulp through the three or four screens. By this means it is better separated, as solid foreign matters, as well as the hard portions, are left in the pump-barrel.

The soft substance is next rolled and kneaded beneath cylinders similar to those already described, either alone or mixed with a few hundredth parts of ultramarine blue, orpiment, zinc-white, vermilion, or half a hundredth part of lamp-black (calcined), to make a blue, yellow, opaque white, brown, red, or black paste. Three or four hundredth parts of sulphur may be added if it be wished to vulcanize the material afterwards by merely heating it up to 275° to 285°. If the paste while being kneaded is not sufficiently soft, from half to one part of essence of turpentine may be added, which makes altogether three and a half or four parts for one part of caoutchouc: the paste is then ready to be laid on the fabrics. This is effected in the following manner.

In a part of the factory specially devoted to that purpose, well ventilated, and free from dust, a double frame supports, at a distance of 28 to 29 mètres apart, two cylinders 60 centimètres in diameter, and $1^m \cdot 50$ in length, revolving upon their axes, which are placed horizontal and parallel to each other. Over these two cylinders is passed a stout endless band, which may be tightened at will by means of binding screws upon the bearing blocks of the axis of one of the cylinders. The fabric $1^m \cdot 30$ to $1^m \cdot 33$ broad, which it is required to overlay with caoutchouc, is laid upon this band, and the two ends are sewn together, so that it too forms a continuous circuit and follows with the rotation of the cylinders all the motions communicated to the band. A transverse bar of wood, or better of iron, forming a kind of knife with a rounded edge, may be brought into contact with the fabric by two adjustment-screws; this serves to limit the thickness of the layer. A second transverse bar, parallel to the former, with rounded angles and covered with swan-skin, is placed under the endless band to keep the fabric perfectly horizontal and to regulate the pressure of the upper bar.

All being thus arranged, the paste is poured upon the fabric in front of the bar; and the two cylinders being set in motion, the band and the fabric upon it move along together, dragging the paste beneath the bar with a speed of 10 mètres a minute, so that in seven minutes the whole 69 mètres are covered. It was necessary formerly to wait at least two hours for the essence to evaporate before applying a second layer; in this way from twenty-eight to thirty hours were requisite to apply fourteen layers. But Guibal and Cuminge have reduced the whole duration of this operation to two hours by means of a new arrangement.

This arrangement consists in placing under the band at a distance of 1 mètre from the transverse bar A, Figs. 4197 to 4201, the two latter of which show the details of the bar or knife, a closed vessel, being a kind of box of plate iron B C D slightly bulging, as shown in Figs. 4197 to 4199, upon which the band rests throughout its whole breadth and for a length of 5 mètres. Into this vessel steam passes freely through a pipe E from a boiler in which the temperature is kept at 194°. The condensed steam flows out through the tubes $b' c'$ towards the water return. The heat thus transmitted to the thin layer of caoutchouc paste hastens the evaporation of the essence of turpentine employed. Besides this, a refrigerator F, formed of two slabs placed together like a roof, and having a slope of 45°, is erected over the fabric for a length corresponding to that of the vessel beneath. As the vapour exhaled from the paste meets the slabs, it is cooled by the water which falls upon them continuously from above from a pipe G parallel to their ridge, and pierced with holes on each side. The equal dissemination of the water over the whole surface is secured by fixing upon each slab a piece of coarse linen or canvas. The vapour of essence of turpentine or of *benzine* is condensed against the lower faces of the slabs, and, flowing down, collects in the channels I, which take it to a common receptacle J on each side.

In seven minutes each layer is spread and dried upon the fabric, which is wound alternately upon the two reels K L, so that the fourteen layers are laid on in two hours. As soon as the last layer is sufficiently dry, the fabric is wound off upon a portable reel. If the caoutchouc contain 3 or 4 per cent. of sulphur worked into it by kneading, it may be vulcanized by simply exposing the fabric to a temperature of 270° to 275° in a cylinder with a double envelope heated by steam up to 291° under a pressure of four atmospheres. The following composition is used by Guibal as a cheap and durable coating, free from all unpleasant smell;—

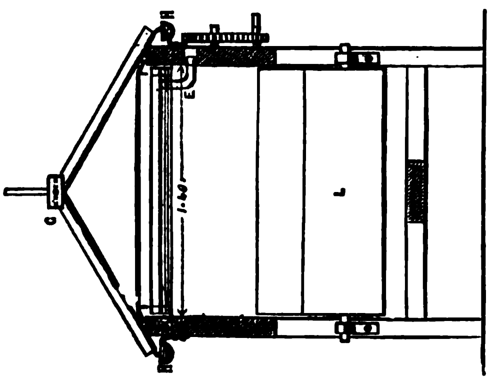
Purified caoutchouc	33
Ground litharge	50
Carbonate of lime	10
Lamp-black	2
Sulphur	5
	100
Benzine	100

The above method of vulcanizing is, however, employed only for linen fabrics; for silk and woollen goods would become crisp at so high a temperature. These are hung up in a cylindrical stove 3 mètres in diameter and 5 mètres high, which is heated for twelve hours by steam circulating under a pressure of four atmospheres through tubes at the bottom. During one and a half of the twelve hours the temperature is at 268° to 275°. These fabrics, which are intended for cloaks and hunting and shooting overcoats, are coated with a composition consisting of 30 parts of caoutchouc, 50 of porphyrized litharge, 10 of chalk, 2 of lamp-black, and from 4 to 5 of sulphur.

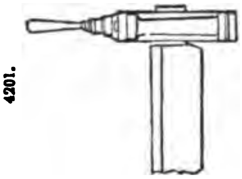
The same arrangements serve to coat a fabric upon both sides, by simply turning it over upon the endless band; in such a case more than five or six coatings are seldom laid upon each side. In the same way, four or five layers may be put between two pieces of cloth by laying two or three coatings upon each, and passing the two, placed face to face, between two rollers, which would make them adhere firmly.

The same machine is used to make large thin sheets of caoutchouc alone, either pure or mixed with pulverulent matters, such as sulphur and the colouring substances, zinc-white, ultramarine, ochre, lamp-black, and so on. In this case, a dressing of paste and two or three layers of a mixture of equal parts of molasses and gelatine must be first spread upon the endless band, which is stretched between rollers 14 mètres apart, occupying the place of the reels K L. This coating, which is sufficiently dry not to stick to the substances placed upon it, keeps supple for a long time by reason of the hygroscopic property of molasses. Upon this consistent coating as many as forty layers of the caoutchouc paste is laid to obtain a thickness of 1 millimètre; each layer, spread in ten minutes, requires one hour to dry, so that forty hours are required to spread and dry the forty layers. The sheet of caoutchouc is easily detached from the band, as the gelatinous coating prevents adhesion; it is afterwards sprinkled with very fine sifted talc and wound on a reel.

4199.



4201.



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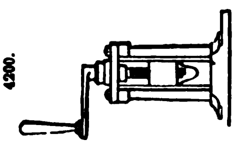
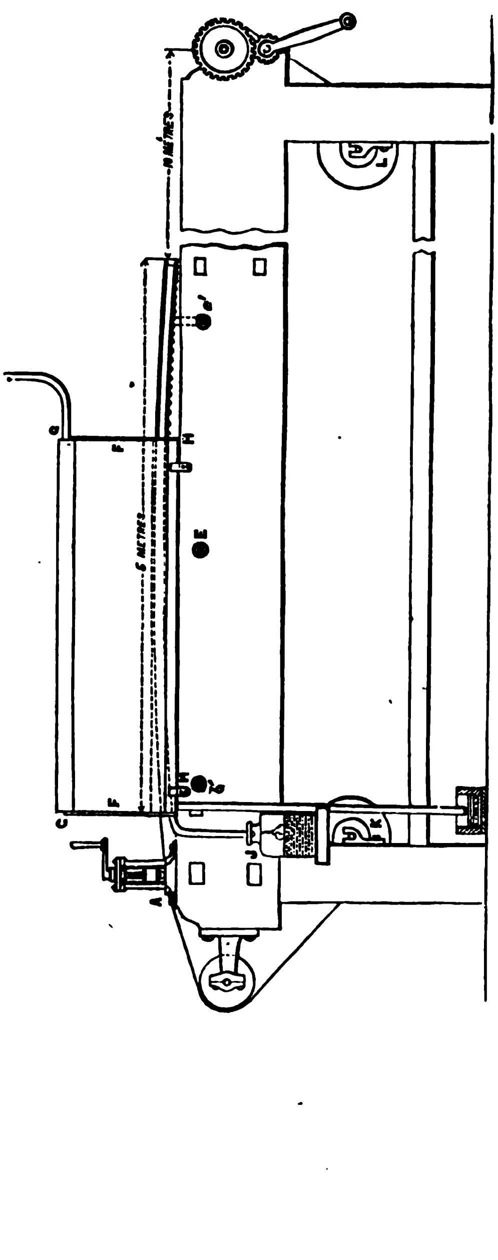
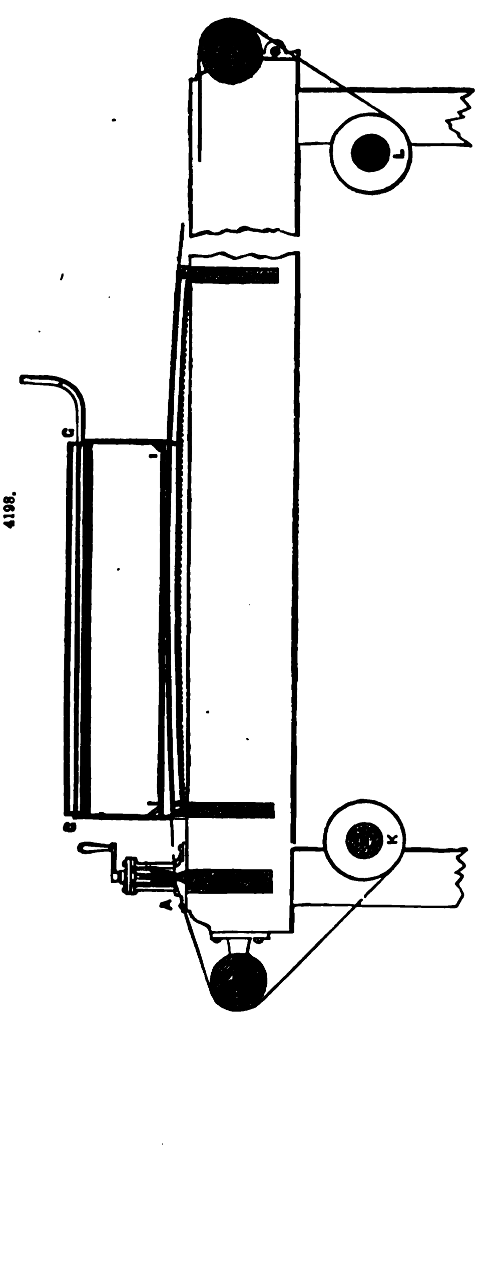


4197.



4198.



Articles of all shapes may be made out of this sheet, and afterwards vulcanized by simply heating them up to 275°, if sulphur has been previously mixed with the paste. The excess of sulphur may be removed from the articles after they are vulcanized, by immersing them for an hour in a boiling solution of soda or caustic potash; and the surface may be made softer by passing them through a bath of hydrochlorite of potash (Javelle liquor) heated up to 140°.

The method of dissolving and distending caoutchouc by a mixture of sulphuret of carbon and caoutchouc cold in a closed vessel, and then kneading in a press which forces the paste through fine wire gauze, is employed to prepare a coating to be put between two fabrics unwound from two cylinders, and uniting beneath the rollers of a rolling machine. The paste possessing sufficient fluidity holds the two together, and renders them waterproof. The sulphuret of carbon is more completely and more quickly volatilized than essence of turpentine, and leaves less smell. To moderate the evaporation and increase the adhesion, benzine may be substituted for a portion of the sulphuret of carbon.

The rolling machine and cylinders should be enclosed and well ventilated to protect the workmen from the noxious influence of the sulphuret of carbon.

Uses of the Sheets and Strips of Caoutchouc cut by the Machine-knife.—A great variety of articles may be made of these pieces before they are vulcanized, whether they contain 5 or 6 per cent. of sublimed sulphur, the action of which will show itself later by being raised to a temperature of 275°, or whether vulcanization is to be effected cold by chloride of sulphur dissolved in sulphuret of carbon. In any case, these pieces of caoutchouc, rendered supple by a temperature of 76° to 86°, are formed into all sorts of shapes before they are vulcanized; and if the articles produced are small figures or balls from 5 to 8 millimètres thick, their regularity is perfected by means of a mould into which they are placed hot, a temperature of 212° to 248° being sufficient to ensure correctness of form, and from 271° to 275° to fix the form acquired by vulcanizing the material. We shall give a sufficient idea of the processes employed in making a vast number of articles of this nature by describing the manufacture of hollow balls.

Small hollow balls of 8 to 12 centimètres in diameter are made of strips of caoutchouc mixed with sulphur, reduced to a thickness of 5 or 6 millimètres, by rolling, or by being cut with the oscillating knife. In all cases, four segments of a sphere are cut out of these strips according to models, and the edges joined by pressing them between the thumb and finger or with a caoutchouc paste, sulphur, sulphuret of carbon, and benzine, care being taken to enclose as much air as possible. They are then placed between the two hollow half-spheres or shells of a grooved mould a little smaller than the ball formed of the segments; the two shells are held together by thumb-screws. When all the moulds have been filled and screwed up, they are placed in the steam vulcanizing cylinder; here each ball swells by reason of the air inside dilating under the influence of the temperature, presses against the smooth or grooved face of the mould, and soon after the temperature has reached 266° becomes set by being vulcanized; the pressure of the confined air is sufficient to keep the ball distended. These balls are used as indoor toys, where harder ones would be dangerous.

Larger balls, such as those used for foot-ball and similar games, are made in the same way; but the necessity for greater consistency and elasticity requires the insufflation of compressed air. This was formerly effected by placing a small round piece of caoutchouc in the form of a washer on the inside to double the thickness at that part, and, after the ball was moulded and vulcanized, inserting, through a hole bored in this double thickness, the end of the blow-pipe of a compression-pump. When the ball was sufficiently distended, the pipe was withdrawn and a small conical iron plug inserted in its place. This manner of closing the hole was, however, defective, for a shock such as that caused by a blow or a bound soon blew out the plug, and the ball collapsed. This accident is now avoided by means of a very simple contrivance. Instead of putting a little disc of caoutchouc mixed with sulphur on the inside before the ball is closed up, as described above, a thicker disc, free from sulphur, is so applied. When these balls have been moulded and vulcanized in the steam-cylinder by a temperature of 275° in the manner already described, they are too feebly distended to enable the pressure inside to withstand the external pressure. They may, however, be easily distended to a greater degree, and kept in that state. This is done by simply inserting the point of a pipe communicating with a blowing machine. When the ball is sufficiently distended, the pipe must be withdrawn without allowing any of the compressed air to escape. This difficulty is surmounted by squeezing between the thumb and finger the thick disc of caoutchouc on the inside, which is still in its normal state, since it contains no sulphur. As it still retains its adhesive property, therefore, the pressure of the fingers is sufficient to make the sides of the aperture adhere, and so close it hermetically.

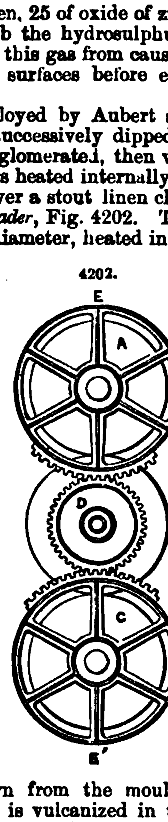
India-rubber Carpets.—We have already referred to the carpets, or mats, formed of a single piece of caoutchouc, manufactured by M. Gérard. In fabricating these articles he places a thick sheet of rolled caoutchouc between two cast-iron chests 50 centimètres in depth, strengthened by strong stays, and closed by a thick bolted lid of cast iron. The lower chest bears the rectangular moulds of cast iron, having hollows and projections sculptured and engraved upon them, in order to produce, by means of a heavy pressure transmitted by two iron screws, deep impressions; regular designs, bordered by a truly artistic framing of bas-reliefs, or medallions, are thus obtained between the faces of this kind of large embossing machine. At the moment when the pressure produces its effect, steam, under a pressure of four atmospheres, is injected into each of the two chests, so as to raise the temperature throughout the whole mass during one hour and a half to 284°. When sufficiently cooled, the screws are loosened and the caoutchouc removed.

It is possible in practice to obtain carpets two, three, or even twenty-five times this length, by continuing, one after the other, two, three, or twenty-five similar impressions upon the same sheet of caoutchouc. Care must be taken, in joining the moulds, to leave the contiguous portions exposed to the air, to avoid vulcanizing them a second time, which would render such parts of the carpet too hard.

The paste should be formed with 50 parts of caoutchouc, 15 of ravelled linen, 25 of oxide of zinc, 4 of sulphur, 5 of lime, and 6 of chalk. The 5 parts of lime serve to absorb the hydrosulphuric acid which is continually generated during the sulphuration, and to prevent this gas from causing flaws. The sticking of the moulds may be prevented by rubbing their surfaces before each pressure with a greasy cloth, or moistening them with soapy water.

The Manufacture of Machine Belts.—The following is the method employed by Aubert and Gérard in the manufacture of strong machine belts. The raw caoutchouc successively dipped in warm water, passed through the crushing machine, washed, dried, and agglomerated, then well kneaded with ·05 of its weight of finely-powdered sulphur between cylinders heated internally by steam to 120° or 140°, gives a very homogeneous paste, which is spread over a stout linen cloth and made to penetrate all its interstices by means of a machine called a *Spreader*, Fig. 4202. This machine is composed of three hollow cast-iron cylinders, A, B, C, of equal diameter, heated internally by steam introduced through the axis of a hollow spindle turning in a stuffing box; these cylinders are each furnished with a cog-wheel. Motion is imparted to the cylinder B, and transmitted by its toothed wheel D to each of the other wheels E, E′; the diameter of each of which is double that of the wheel D. It follows from this arrangement that the cylinder B turning twice as fast as each of the other two, the stout cloth, 1 mètre in breadth and 10 to 50 mètres in length, which passes between these cylinders receives the caoutchouc paste with so great a friction that it is penetrated by it, and the sheets thus prepared being placed one upon another, in number from three to ten, and passed between the heated cylinders of a rolling press, are formed into a solid mass. They are then cut up by a machine-knife according to the size of the wheels which they are intended to drive. To give them greater strength, and to render their edges smooth, they may be enveloped in a cloth prepared in the same manner and the joint covered with a narrow strip, which will render the whole envelope solid with the subjacent tissues.

4202.



Vulcanization is then effected by placing the belts in wrought-iron moulds forming a rectangular groove, which has been previously soaped, and which then receives an equally smooth plate of iron extending 10 or 12 millimètres beyond it. All the moulds thus filled are placed upon the lower chest of the vulcanizing press previously described. When the whole of the surface of this is covered with moulds the upper chest is lowered, by means of an endless screw working into the two cog-wheels which turn the screws of this press, and during the time that the pressure is exerted the temperature in the moulds is raised, by steam under a pressure of four to five atmospheres, to 284°. Under these conditions an hour suffices to vulcanize the belts. Then the upper chest is raised, the belts withdrawn from the moulds, and replaced by a second length in the same moulds. This second length is vulcanized in the same manner as the first, and the process is repeated until the whole length of belt has been vulcanized.

As contact with the iron distributes the heat rapidly, the time necessary for vulcanizing is, comparatively with vulcanizing by confined steam, diminished by one-half, from one hour to one hour and a half, instead of two hours to two hours and a half. The extremities of the moulds are slightly hollowed out, in order that in changing the place of the belt it may not be found twice vulcanized near the line of demarcation.

Hard India-rubber.—About the year 1848 a branch of industry was founded in America by Goodyear, in which advantage was taken of the properties of caoutchouc hardened by its combination with sulphur, in proportions much larger than those which constitute the compound known under the name of *Vulcanized India-rubber*.

The following is the method of preparing this substance;—

The raw materials are obtained from the products of a cheap and inferior quality, imported from Java and India in blocks containing foreign matters requiring a special purification. The lumps, more or less *voluminous*, of this raw caoutchouc, are put into tanks containing water which is kept at a temperature of from 110° to 120° during thirty-six to forty-eight hours. When these are sufficiently softened, they are cut up by means of a large and sharp thin-bladed knife into pieces of about 1 kilogramme in weight and between 6 and 12 centimètres thick. These pieces are crushed and kneaded between two cylinders slightly wetted, turning in contrary directions, the one making one revolution, the other two-thirds of a revolution a minute. The strips thus obtained, rough and full of holes, are next torn into small shreds by means of a machine similar to that employed for preparing the pulp in the manufacture of paper. When the continuous flow of water in this machine has entirely eliminated the earthy and other foreign matters, the caoutchouc is lifted out in a kind of floating pulp, and dried upon cloths fixed in frames; care must be taken not to raise the temperature of the current of air to a degree which would render the caoutchouc adhesive and cause it to retain a portion of the water.

The dried substance is then kneaded for about an hour by being made to pass several times between two cylinders, heated by an injection of steam to between 120° and 140°.

The pasty consistency of this mass admits of the easy incorporation with each 100 kilogrammes of caoutchouc of 50 of stone sulphur, reduced to powder and passed through a brass sieve No. 90 to 100 or 110 (that is to say, showing, when viewed under a lens, 90 to 110 threads upon each side of a square of 27 millimètres).

The sulphur being intimately blended and uniformly spread throughout the mass, the cylinders are brought closer together by means of regulating screws acting upon the bearing blocks, so as to reduce the paste to a sheet of the required thickness (of 2 to 7 millimètres, but more usually of 3 to

4 millimètres) for the manufacture of combs and common articles; the sheet is cut up according as it is rolled, into tablets of 40 centimètres in breadth and 60 centimètres in length.

These soft tablets are received upon frames, upon which is stretched moistened canvas, and plunged into warm water at about 80°, in order to take off the excess of heat and render them more firm, and to effect the contraction which otherwise would be produced at the moment of vulcanizing, and which would detach them from the sheets of tin or of glass. They are then dried and placed upon sheets of tin or glass, previously covered with a thin layer of lard; then, to ensure their contact, a very smooth iron roller is passed over it, and, to prevent the caoutchouc from sticking to the roller, the latter is powdered with silicate of magnesia (talc).

After remaining twenty-four hours in a horizontal position, which increases the consistency of the tablets, the plates thus charged are placed upon iron frames mounted on a bed-plate which keeps them in a position inclined at about 45°, in order, on the one hand, that the tablets may not run as they become soft during the sulphuration, and, on the other hand, that the drops of condensed water may run off without staying on the paste.

The bed-plates, mounted upon wheels, are run upon rails into a stout plate-iron cylinder, 1 mètre in diameter and 6 mètres in length.

This is closed by a kind of door of cast iron having a circular flange, which fits into a groove round the edge of the cylinder half filled by a roll of supple alkaline caoutchouc mixed with ·25 of tow. The door being firmly closed, steam is injected through a pipe full of holes fitted to the bottom throughout the whole cylinder.

The steam, furnished by a boiler under a pressure of five atmospheres, is gradually distributed so as to raise very slowly, in two or three hours, the temperature in the interior of the cylinder to 275°.

This temperature is maintained for seven hours.

If tablets of caoutchouc of 10 to 12 millimètres thick had been employed, it would have been necessary to raise the temperature more slowly, say in four hours, to 275°, and to keep it there during eight hours.

The injection of steam is then stopped, and they are allowed to cool slightly, after which the air is readmitted into the cylinder. The door may then be removed, the frames withdrawn, and when completely cold the caoutchouc lifted off, the tablets having become very firm by the combination of the sulphur with the caoutchouc. If the proportion of sulphur were augmented, or if the temperature were raised too high, the product would become harder, but it would be too fragile. It has been proved that by mixing an excess of sulphur a hard and brittle compound can be obtained, containing ·48 of sulphur combined; whilst hard india-rubber of good quality should contain only ·33 of sulphur.

During the sulphuration in the cylinder, the steam in condensing falls in drops of water upon the yet soft tablets. The water bringing with it the rust (oxide of iron) formed upon the inner surface of the cylinder, these substances often penetrate deep enough to form bubbles and faults in the thickness of the tablets, and so lessen much the value of the articles made from them.

A method could probably be devised to prevent these defects, either by maintaining the pieces of caoutchouc in a vertical position between two sheets of tin, or by placing, above the bed-plate which carries the inclined frames, two sheets of tin in the form of a ridge-roof; a roof of this kind would receive the drops of water from above and would cause them to drain off beyond the tablets.

After the tablets are manufactured, they are employed principally as raw materials for combs. For this purpose the tablets are cut into the usual forms by means of a narrow saw, called a fret-saw, which follows the outlines already traced by a steel point. The pieces thus cut up are thinned towards one of their edges, like a sword blade, by means of planes, and further smoothed by rubbing them on a slate. The teeth are then cut by a circular saw. Nothing then remains but to polish them, which is easily accomplished by rubbing them with a mixture of powdered pumice-stone and tallow.

Pieces of various shapes may be sawn out, turned, or planed, and then easily bent, by dipping them for some minutes into boiling water, or by heating them in a stove. If they are plunged into cold water after they are bent, they will immediately set in the acquired form.

The thick sulphured paste of caoutchouc may easily be spread upon bronze moulds, bas-reliefs, and these medallions afterwards exposed in the steam-cylinder to the temperature of 275°; when cold they retain the acquired forms, with the polish of the moulds.

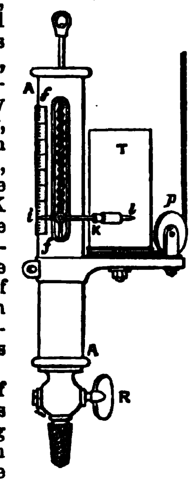
INDICATOR. Fr., *Indicateur;* Ger., *Indicator;* Ital., *Indicatore.*

The steam-engine *indicator* is an instrument for ascertaining the pressure of the steam in the cylinder of steam-engines, and the law of its variation during expansion, and during a double stroke of the piston. The instrument was invented by Watt and improved by MacNaught. In its simplest form, it consists of a small hollow cylinder A A, Fig. 4203, which may be screwed upon the head of the cylinder of the steam-engine; steam is let into it by means of the cock R. A piston, the rod of which is visible through the longitudinal aperture *f f*, works in this cylinder A A, and through the upper end. The rod is surrounded with a spiral spring fixed to the small piston and to the upper end of the cylinder A A. The steam, in virtue of the pressure which it exerts upon the small piston, compresses this spring; and, if the spring is carefully made, the quantity by which it is compressed in the vertical direction is proportional to the pressure exerted upon the small piston; so that the pressure in the cylinder of the engine is measured by the quantity by which the small piston rises above its initial position, which position answers to a pressure of *o*, or to an absence of pressure. This displacement of the small piston is measured on the outside by means of a style *i* K, fixed to the rod by a stud projecting through the longitudinal opening. The end *i*, of this style moves over a divided scale fixed to the cylinder, and this gives the measure of the pressure.

The instrument is very valuable, even when reduced to the parts which we have just described, as it enables us to ascertain the pressure in the steam-cylinder, a pressure that is always

considerably less than that exerted in the boiler, and which is measured by the gauge. But the improvements which have been made in it enable it to register the variations of pressure, and to express the law of the variations by a curve. The following description will show how this is done;—Upon a support fixed to the cylinder A A, is a drum T, revolving about its axis and having a strip of paper rolled round it. A groove on the lower end of this drum holds a cord which passes over a pulley p, with a horizontal axis and fixed upon the same support, and is carried up vertically to a horizontal arm or stud on the engine piston-rod. It follows from this that the drum turns upon its axis by a quantity proportional to the displacement of the piston of the engine. A spring, similar to the main-spring of a watch, fixed inside to the side of the drum and to a fixed point, being compressed during the rotation of the drum, corresponding to the upward stroke of the engine-piston, brings back the drum to its original position during the downward stroke. To the end K of the style i K, is fitted a pencil, which makes an obtuse angle with the style, and the point of which rests upon the drum. During the simultaneous motion of the small piston and the drum, this pencil traces upon the surface of the latter a curve which expresses the law of the variation of the pressure in the engine-cylinder; for the displacements of the pencil in the vertical direction, reckoning from the position corresponding to a pressure of o, are proportional to the pressure, and the rotation of the drum is proportional to the distance traversed by the engine-piston.

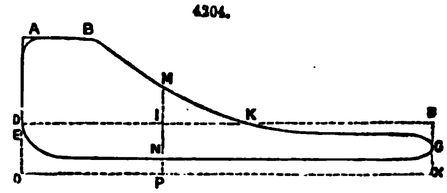
4203.



The arrangement we have described supposes that the circumference of the groove of the drum is at least equal to the stroke of the piston; but as this condition cannot always be conveniently fulfilled, the cord on coming from the groove is made to pass first over a little windlass moving with the pulley p, and having the same axis; a second cord, attached to the groove of the pulley, to which a sufficiently large radius may be given to make its circumference exceed the stroke of the piston, is carried up vertically and fixed to the engine-piston in the way described above. By this means the indicator may be applied to widely-different strokes.

If the sheet of paper which was rolled round the drum be unrolled after the experiment, we obtain a curve or diagram similar to Fig. 4204, and representing the law of the variation of the pressure during a double stroke of the piston. In a previous experiment, and before the indicator was screwed upon the cylinder of the engine, the drum was turned, and the pencil traced the horizontal straight line O X, which corresponds to a pressure of o, since the pressure of the atmosphere was then acting upon both ends of the little piston. The straight line D H was also drawn corresponding to one atmosphere, which is very easy, knowing the compression to which the spiral spring is subjected under the pressure of a given weight. Then let M P be the ordinate of any part of the curve with respect to O X, which ordinate meets in I the horizontal D H. The ratio of M P to I P will express the ratio of the pressure of the steam in the cylinder to the pressure of the atmosphere, for the position of the piston corresponding to a fraction of the stroke marked by the ratio of O P to O X (O X being the whole stroke). Instead of expressing the pressure by a ratio, it may be expressed by a number of kilogrammes to the square centimètre, by merely choosing a scale in which I P shall represent $1^k \cdot 033$, or by a number of pounds to the square inch by making the corresponding suppositions.

4204.



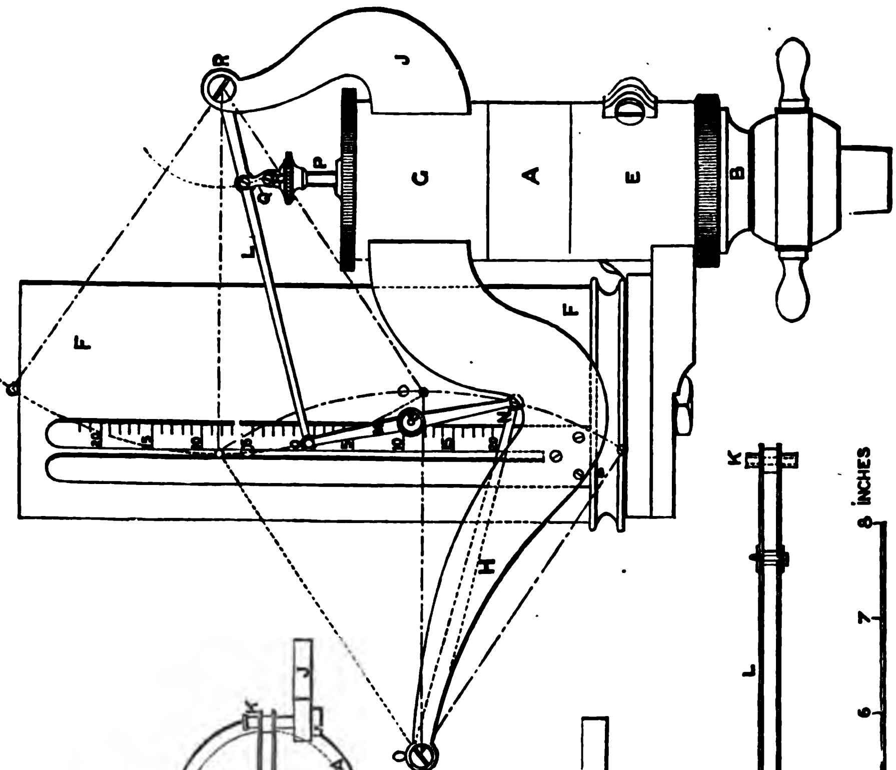
It will be seen by a reference to the diagram that the portion A B corresponds to the period of admission of the steam into the cylinder. The portion B M C corresponds to the period of expansion; the pressure, which was greater than that of the atmosphere, becomes equal to it for the position of the piston corresponding to the point K, after which it becomes less. The portion C N D corresponds to the period of emission during which the pressure is that of the condenser. This latter portion of the curve joins itself to the first at the end of this second stroke, and the diagram is the closed curve. When a certain advance is given to the admission or the emission, every circumstance of the motion is represented by the diagram.

This diagram enables us also to calculate the work corresponding to a stroke of the piston. Since the ordinate M P expresses the pressure, and the abscissa O P the distance passed over, the work of the steam upon the piston during a stroke is represented by the area O A B C X O. But for a similar reason, the work exerted upon the same face of the piston during the following stroke is expressed by the area O E N C X O. Consequently, the work developed upon the piston during one stroke is the difference of the two preceding, that is, it is expressed by the area comprised in the closed curve forming the diagram. This area may be computed by means of the *planimeter*, or by an approximative formula.

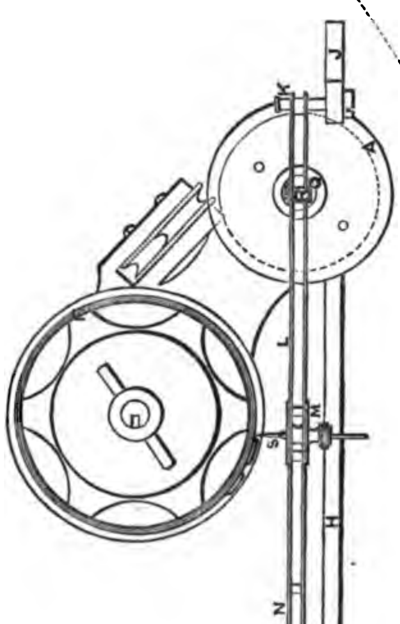
The form of steam-engine indicator formerly in general use was the MacNaught Indicator, just described, in which the piston and its guiding rod have the same range of motion as the pencil; but as the piston and rod were necessarily made quite heavy, and their range of motion extensive, in order to produce delineations on a sufficiently large scale, the momentum of these parts was so great, and the tremulousness of the spring so considerable, as to render the instrument unserviceable for application to engines having rapid movements. These defects have been remedied in the Richard's Indicator, the invention of Chas. Richards, of Connecticut, U.S.

Fig. 4205 is a plan of this instrument; Fig. 4206 is a side elevation; Fig. 4207 is a vertical section through the centre of the spring-case A; and Figs. 4208 to 4211 show parts of the instrument in detail.

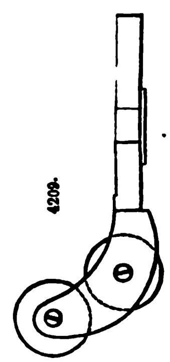
4206.



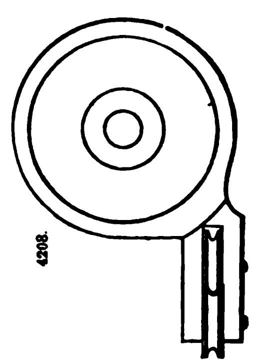
4205.



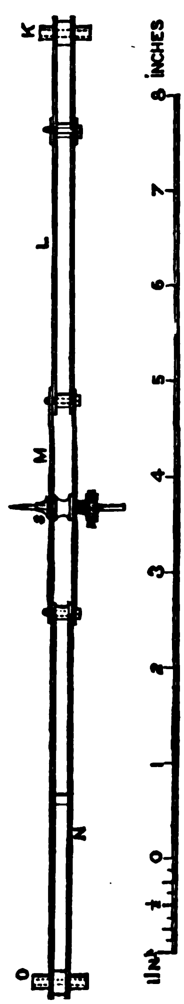
4209.



4208.

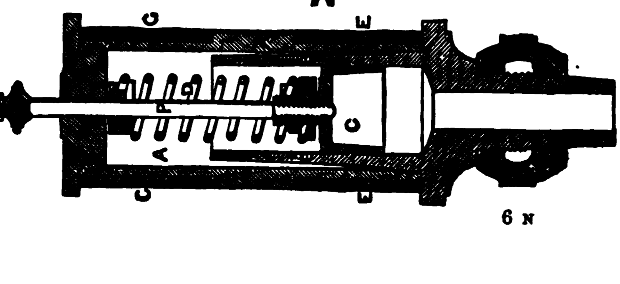


4210.



4211.

4207.



A is a cylindrical case containing a small steam-cylinder B, in which moves a piston C, the movements of which are regulated by a spiral spring D. These parts are constructed and arranged in a manner similar to, but are much shorter than the corresponding parts of, an ordinary MacNaught indicator, making delineations on the same scale. To the outside of the case A is secured a ferrule E, an arm from which supports a cylindrical paper-holder F, which, in construction and arrangement, is similar to the paper-holding drum of a MacNaught indicator, and it receives the proper reciprocating movements in the same manner. Around the upper part of the case A is a ferrule G, to which are attached two arms H and J, one of which, J, supports the fulcrum pin K of a light lever L, the extreme end of which lever is jointed to the end of a lever or link M, the opposite end of which is jointed to the extremity of a delicate lever or radius bar N, the fulcrum pin O of which is supported by the arm H. To the lever L, at a point distant from its fulcrum K, about one-fourth of the length of the lever, the rod P of the piston C is connected by means of a forked link Q, which is jointed by a knuckle R to the upper end of the rod P. In the centre of the link M is a holder for the pencil S, which receives from the piston C, through the lever L, a range of perpendicular motion about four times greater than that of the piston, and the levers L and N are so proportioned and their fulcrums are so adjusted that the marking-point of the pencil S is caused to move in a straight line in the same manner that the parallel motion of a steam-engine causes the end of the piston-rod to move in a straight line. The movements of the lever are indicated in Fig. 4206.

The indicators made by Elliot Brothers, London, the sole manufacturers in England, are of a uniform size; the area of the cylinder is one-half of a square inch, its diameter being ·7979 of an inch. The piston is not fitted quite steam-tight, but is permitted to leak a little; this renders its action more nearly frictionless, and does not at all affect the pressure on either side of it. The motion of the piston is $\frac{25}{32}$ of an inch, and the motion of the pencil, or extreme height of the diagram, is $3\frac{1}{8}$ in. The paper cylinder is 2 in. in diameter, and the length of the diagram may be $5\frac{1}{4}$ in., if this extent of motion is given to the cord. The diagram is drawn by a pointed brass wire on metallic paper. This is a great improvement over the pencil; the point lasts a long time, cannot be broken off, and is readily sharpened, and the diagram is indelible. The steam-passage has two or three times the area usually given to it. The stem of the indicator is conical, and fits in a corresponding seat in the stop-cock, where it is held by a peculiar coupling. The leading pulleys may be turned by some pressure to give any desired direction to the cord, and will remain where they are set.

The Springs.—In order to adapt this indicator for use on engines of every class, springs are made for it by Elliot Brothers to ten different scales, as follows;—

No. 1, $\frac{1}{8}$-in. motion,	shows 1 lb.	pressure	on the sq. in.;	indicates	from	− 15	to	+ 10
„ 2, $\frac{1}{12}$	„	„	„	„	„	− 15	„	+ 22·5
„ 3, $\frac{1}{16}$	„	„	„	„	„	− 15	„	+ 35
„ 4, $\frac{1}{20}$	„	„	„	„	„	− 15	„	+ 47
„ 5, $\frac{1}{24}$	„	„	„	„	„	− 15	„	+ 60
„ 6, $\frac{1}{30}$	„	„	„	„	„	Atmosphere	to	+ 80
„ 7, $\frac{1}{32}$	„	„	„	„	„	„	„	+ 100
„ 8, $\frac{1}{40}$	„	„	„	„	„	„	„	+ 125
„ 9, $\frac{1}{48}$	„	„	„	„	„	„	„	+ 150
„ 10, $\frac{1}{56}$	„	„	„	„	„	„	„	+ 175

Most of the scales are multiples of 8, and the common rule will measure the diagrams, if the proper scale is not at hand. It will be observed that the five higher scales do not indicate the vacuum. These are so made for the following reasons;—The far greater number of engines which work steam at high pressures do not condense; and, moreover, at these pressures, the scale of the indication necessarily becomes small, while it is always desirable to show the vacuum on a large scale. Spring No. 1 may be employed to indicate the vacuum in engines which work steam at high pressures and with condensation. It can be readily substituted in the indicator, and the diagram given by it will be on a satisfactory scale. It is provided with a stop, which prevents it from being compressed too much, so that a high pressure of steam will not injure it. Moreover, the vacuum being omitted from the scales, which go above 60 lbs., the entire range of the pencil is available for the pressures above the atmosphere, which are therefore shown on a somewhat larger scale. The springs indicating pressures above 60 lbs. will be made, however, to indicate the vacuum also when so ordered.

The springs are tested with a highly sensitive apparatus, designed expressly for the purpose, and are corrected for a temperature of 212°, which is the temperature at which they will work under almost all circumstances, and at which their accuracy is guaranteed.

We extract from Charles T. Porter's work on the Indicator the following practical directions for applying the instrument.

Attaching the Indicator.—When it is practicable, diagrams should be taken from each end of the cylinder. The assumption commonly made, that if the valves are set equal, the diagram from one end will be like that from the other, will be shown by this instrument to be erroneous. This is owing to the difference in the speed of the piston at the opposite ends of the cylinder, which is at the outer end of a direct-acting engine, from 35 per cent. to 66 per cent. greater than at the crank end, the difference varying according to the degree of the angular vibration of the connecting rod. In side-lever or beam engines these proportions are reversed, and the speed of the piston is greater at the upper end of the cylinder. Often also there is a difference in the lengths of the thoroughfares, and in the lead, or the amount of opening, or the point of closing; and many times the valves are supposed to be correctly set, when this indicator will show that they are not. These and many other causes will make a difference in the diagrams obtained from the opposite sides of the piston.

One use of the indicator is in fact to show whether or not the diagrams from opposite ends of the cylinder are alike.

Pipes to be avoided.—The indicator should be fixed close to the cylinder, especially on engines working at high speeds. If pipes must be used, they should not be smaller than $\frac{1}{2}$ in. in diameter and $\frac{3}{4}$ in the bends, and as short and direct as possible. Any engineer can satisfy himself with this instrument that each inch of pipe occasions a perceptible fall of pressure between the engine and the indicator, varying according to its size and number of bends and the speed of the piston. Diagrams have been known to show, from this cause alone, 40 per cent. less pressure than was actually in the cylinder. Probably the diagrams taken from engines generally show in nine cases out of ten the lead or the pressure or both untruly, from the incorrect manner in which the instrument is attached.

Where to connect the Indicator.—On vertical cylinders, for the upper end, the indicator-cock is usually screwed into the cover. Sometimes it is attached where the oil-cup is set, this being removed for the purpose. For the lower end, it is necessary to drill into the side of the cylinder, at a convenient point in the space between the cylinder bottom and the piston, when on the centre, and screw in a short bent pipe, with a socket on the end to receive the indicator-cock. The indicator can be used in a horizontal position, but it will be found much more convenient to put in a bent pipe, and set it vertical. Sometimes it will be necessary to drill in the side of the cylinder, at the upper end also, especially in double-cylinder engines having parallel motions, when the indicator cannot generally be set on the covers. Care must be taken that the piston does not cover the hole when on the centre. No putty is necessary to make these small joints, and it should never be used, as it is liable to clog the instrument. If the screw fits loosely, a few threads of cotton wound round the stem will prevent the escape of steam.

On horizontal engines, the best place for the indicator is on the top or upper side, at each end; if it cannot be placed there, bent pipes may be screwed into the covers or into the side of the cylinder. In other respects follow the directions given for vertical engines. The indicator should never be set to communicate with the thoroughfares. The current of steam past the end of the pipe or the hole reduces the pressure in the instrument, and the diagram given is utterly worthless.

The stop-cock being screwed firmly to its place, screw the indicator down to its seat, turning it to the most convenient position, and make it fast by turning the coupling; then move the guiding pulleys to their proper position to receive the cord, and the instrument is in readiness for use.

Giving Motion to the Paper.—The motion may be taken from any part of the engine which has a motion coincident with that of the piston. For a beam-engine, a point on the beam or beam-centre, or on the parallel-motion rods where these are employed, will give the proper motion; but care must be taken that the cord be led off in the right direction—a requirement which is sometimes overlooked; afterwards its direction of motion may be changed as required.

In some cases it is most convenient to take the motion from a point on the end of the revolving shaft; this is frequently the case on horizontal engines working at high speeds, because then the motion does not need to be reduced. Exact accuracy cannot be got in this way, however, without employing a moving slide, and connecting it with the pin in the end of the shaft by a rod or cord of such length that its angular vibration shall be the same as that of the connecting rod. This will be found generally a troublesome matter; and the engineer will probably prefer in most cases to disregard the error resulting from its omission, which is, that the motion of the paper will be more nearly equal at the two ends of the stroke, being slower than that of the piston at the one end, and faster at the other. The crank or pin from which the cord receives its motion must be on its centre, relatively to the direction of the cord, whatever that direction may be, precisely when the crank of the engine is on its centre. If this requirement is not carefully attended to, the diagram will be worthless.

Generally, on horizontal engines, the motion of the paper is taken from the cross-head. In an engine-room, a strip of deal board may be suspended from the ceiling in such a manner as to permit it to swing backward and forward edgeways by the side of the guides, and motion may be given to it by a pin, secured firmly to the cross-head and projecting through a slot in the board, in which it should fit nicely to prevent lost time on the centres. The board must hang plumb when the piston is in the middle of its stroke. The cord may be connected to this strip of board at a point sufficiently near to its point of suspension to give the required reduction of motion for the paper, and must be led off in a horizontal direction, and then over one or more pulleys in any required direction to the indicator. At high speeds, however, pulleys should be avoided. On portable engines, the motion may be obtained in the manner just described, the lever swinging from a pin supported in a standard about 2 ft. in height, set on one of the guide-bars.

On locomotives having outside connections the motion must be taken from the cross-head. It is indispensably necessary to use only a short direct cord, free from elasticity, and connected to a point the motion of which is reduced from that of the cross-head by positive means. Care must be taken also so to proportion the parts employed for this purpose, that the point at which the cord is connected shall have a positive motion without any fling, a matter not by any means free from difficulty at 250 revolutions a minute. A rock-shaft, turning in bushings, supported by two angle-iron standards, precisely over the mid-position of that point of the cross-head from which the motion is derived, affords perhaps the best means of reducing the motion. A long arm is worked by the cross-head, and a short arm gives motion to the cord. The short arm must be keyed in such a position that when the piston is in the middle of its stroke it will stand at right angles with the direction of the cord, whatever that may be. The direction of the cord may form any necessary angle with the horizontal line, but must be at right angles with the rock-shaft.

On locomotives having inside connections and a single pair of driving wheels, where it is practicable, it will be found to be the better way to take the motion from a pin set in the end of the shaft, and to communicate it by a connecting rod to a point convenient for attaching the cord. The

parts should be all substantially made; the momentum of the connecting rod will be perfectly resisted by the pin.

On oscillating engines, the motion may be taken from the brasses at the end of the pistón-rod. If the stroke is long, it is sometimes difficult to reduce this motion to that required for the paper, and in such cases it is necessary to take the motion from an eccentric on the main shaft to a point as near as possible to the trunnion, and thence to communicate it to the indicator. In all these connections, it is of the first consequence that there be no lost time, which will require to be made up on every centre, and will thus cause the paper to stand still while the piston is moving.

Pulleys of different diameters on the same spindle have been often used as a means of reducing the motion from that of the cross-head, but we do not recommend them; at high speeds it is very difficult to make them answer.

How to take a Diagram.—To fix the paper, take the outer cylinder off from the instrument, secure the lower edge of the paper, near the corner, by one spring, then bend the paper round the cylinder, and insert the other corner between the springs. The paper should be long enough to let each end project at least ½ an inch between the springs. Take the two projecting ends with the thumb and finger, and draw the paper down, taking care that it lies quite smooth and tight, and that the corners come fairly together, and replace the cylinder. The spring used on this indicator for holding the paper will be found preferable to the hinged clamp. A little practice, with attention to the above directions, will enable anyone to fix the paper very readily.

The marking-point should be fine and smooth, so as to draw a fine line, but not cut the paper. It may be made of a brass wire; the best material is gun-metal, which keeps sharp for a long time, and the line made by it is very durable. Lines drawn by German-silver points are liable to fade. A large-sized common pin, a little blunted, answers for a marking-point very well indeed; a small file and bit of emery cloth used occasionally will keep the point in order.

To connect the Cord.—The indicator having been attached, and the correct motion obtained for the drum, and the paper fixed, the next thing is to see that the cord is of the proper length to bring the diagram in its right place on the paper, that is, midway between the springs which hold the paper on the drum. In order to connect and disconnect readily, the short cord on the indicator is furnished with a hook, and at the end of the cord coming from the engine a running loop may be rove in a thin strip of metal, so that it can be readily adjusted to the proper length, and taken up from time to time, as it may become stretched by use. On high-speed engines, it is as well, instead of using this, to adjust the cord and take up the stretching, as it takes place, by tying knots in the cord. If the cord becomes wet and shrinks, the knots may need to be untied, but this rarely happens. The length of the diagram drawn at high speeds should not exceed 4½ in., to allow changes in the length of the cord to take place to some extent, without causing the drum to revolve to the limit of its motion in either direction. On the other hand, the diagram should never be drawn shorter than is necessary for this purpose.

To take the Diagram.—Everything being in readiness, turn the handle of the stop-cock to a vertical position, and let the piston of the indicator play for a few moments, while the instrument becomes warmed. Then turn the handle horizontally to the position in which the communication is opened between the under side of the piston and the atmosphere, hook on the cord, and draw the atmospheric line. Then turn the handle back to its vertical position and take the diagram. When the handle stands vertical, the communication with the cylinder is wide open, and care should be observed that it does stand in that position whenever a diagram is taken, so that this communication shall not be in the least obstructed. The instrument is provided with a stop, to prevent the marking-point from tearing the paper. The arm is to be pressed firmly up to this stop. If the line drawn is faint, the point must be screwed up, and back if the line is too heavy. The elasticity of the parallel arms gives the light pressure required on the paper. As the hand of the operator cannot follow the motions of an oscillating cylinder, it is necessary that the point be held in contact with the paper by a light spring, and instruments to be used on engines of this class are furnished with an attachment for this purpose.

Diagrams should not be taken from an engine until some time after starting, so that the water condensed in warming the cylinder, &c., shall have passed away. Water in the cylinder in excess always distorts the diagram, and sometimes into very singular forms. The drip-cocks should be shut when diagrams are being taken.

As soon as the diagram is taken, unhook the cord; the paper cylinder should not be kept in motion unnecessarily, it only wears out the spring, especially at high velocities. Then remove the paper, and minute on the back of it at once as many of the following particulars as there are the means of ascertaining;—

The date of taking the diagram, and scale of the indicator.

The engine from which the diagram is taken, which end, and which engine, if one of a pair.

The length of the stroke, the diameter of the cylinder, and the number of double strokes a minute.

The size of the ports, the kind of valve employed, the lap and lead of the valve, and the exhaust lead.

The amount which the waste-room, in clearance and thoroughfares, adds to the length of the cylinder.

The pressure of steam in the boiler, the diameter and length of the pipe, the size and position of the throttle, if any, and the point of cut-off.

On a locomotive, the diameter of the driving wheels, and the size of the blast orifice, the weight of the train, and the gradient, or curve.

On a condensing engine, the vacuum by the gauge, the kind of condenser employed, the quantity of water used for one stroke of the engine, its temperature, and that of the discharge, the size of the air-pump and length of its stroke, whether single or double acting, and, if driven independently of the engine, the number of its strokes a minute, and the height of the barometer.

The description of boiler used, the temperature of the feed-water, the consumption of fuel and

of water an hour, and whether the boilers, pipes, and engine are protected from loss of heat by radiation, and if so to what extent.

In addition to these, there are often special circumstances which should be noted.

How to change the Springs.—Unscrew the coupling from the end of the piston stem, the cover from the cylinder case, and the spring from the piston and cover, introduce the new spring, and screw all firmly up again.

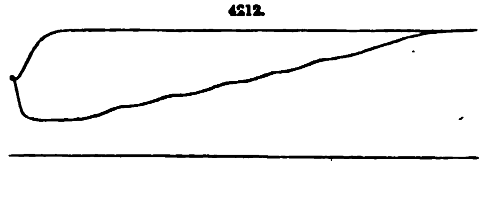
The lengths of the springs for the different scales are so proportioned to each other, that the pencil will always come to the proper position for drawing the atmospheric line. In putting in the spring No. 1, the head from which the barrel projects to stop the compression of the spring should be screwed to the cover and not to the piston. Be careful that the heads are screwed up firmly to the piston and cover.

The spring which gives reaction to the paper cylinder is liable to break after considerable use, especially on engines running at high speeds, for which reason this cylinder should never be left to run unnecessarily. When breakage occurs a new spring can be readily substituted, as follows. Set the indicator on the engine, if there is no other convenient means for holding it firmly, and remove the cover of the spring-case and the broken spring. Then hook the new spring on to the hook projecting from the ferrule on the arbor, coil it into the case, and hook the end on the rim; see that it is coiled in the same direction with the cord. If the spring has not sufficient strength to keep the cord quite tight, another coil must be given to it, but it should not be coiled any tighter than is necessary for this purpose.

Use of the Diagram.—The custom was introduced by Watt, and has since been generally followed in England, to designate the size of engines, in measures of horse-power. Watt ascertained by experiment that the power of London draught horses, exerted with ordinary continuance, was to lift 33,000 lbs. one foot in a minute, and this is now employed, wherever English measurements are used, as the unit of measurement of the actual power of steam-engines.

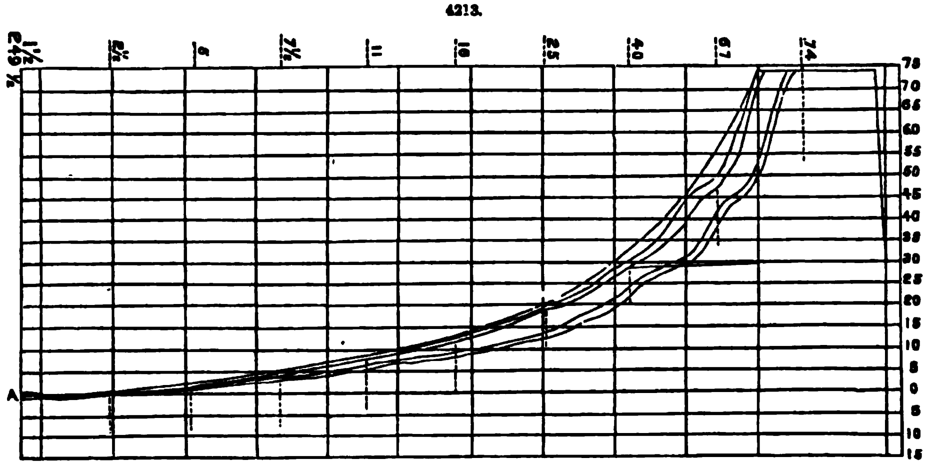
When this measurement was introduced, steam was used only at the atmospheric pressure, or 14·7 lbs. on the square inch, of which 4·7 was considered to be lost by imperfect condensation, and 3 lbs. by the friction of the engine, leaving 7 lbs. for effective pressure upon the piston, and the speed of piston employed was about 220 ft. a minute. At the present day, pressures are employed varying from one to ten or twelve atmospheres, the former, however, being now rarely met with, and the speeds of piston range from 220 to 1000 ft. a minute. Originally, the number of horse-powers defined at once the size and the power of the engine; but when a variety of pressures and speeds came to be employed, the same expression could no longer answer both of these purposes, and a distinction was introduced and still prevails between the nominal and the actual horse-power, the former being applied to th size of engines, irrespective of the pressure or speed employed, and the latter to the power which they exert. The term nominal horse-power has, moreover, acquired a variety of significations in different localities, and it has become difficult to tell, in any case, precisely what is meant by it.

4212.



The indicator furnishes one of the data for ascertaining the actual power exerted by the steam-engine; namely, the mean or average pressure of steam during the stroke, on each square inch of the piston; or, more accurately, the excess of pressure on the acting side of the piston to produce motion, over that on the opposite side to resist it. It is of no consequence, in this respect, what the character of the diagram may be, whether most wasteful,

4213.



like the one shown in Fig. 4212, or most economical, like Fig. 4213. For the purpose of ascertaining the power exerted, we have merely to measure its included area, and so get the mean

pressure on a square inch during the stroke, which this area represents. This pressure being multiplied into the whole number of square inches, and the product by the mean or average speed of the piston, in feet a minute, gives the total number of pounds of force acting through one foot in a minute, and by dividing this by 33,000, we obtain the gross power of the engine in actual horse-powers. The English unit of force is the foot-pound; and 33,000 foot-pounds exerted in one minute make a horse-power.

In order to ascertain the effective power, however, there must be deducted from the gross power the friction of the engine, or the power required to drive the engine alone at the same speed, which, except in the case of vessels with the wheels submerged, the indicator generally enables us to ascertain; and also the increase in this friction which arises when the resistance is being overcome, which the indicator does not show. The amount of this latter is not generally known with any accuracy; but we know that the percentage of loss from this cause diminishes as the size of the engine is enlarged, because the increase in the motion of the surfaces in contact is much slower than the increase in the area of the piston, and also that it varies according to the nature of the lubricating material employed, and the degree of completeness attained in the separation of the surfaces by means of it. Five per cent. is usually allowed for this increase of friction, but it may in fact be considerably more or less than this. On small engines, the friction-brake can be applied, to show the amount of effective power exerted, and a comparison of this with the gross power, and with the friction of the engine alone, as shown by the indicator, will exhibit the increase of friction occasioned by different amounts of resistance, and show the value of different lubricants, and the utility of extended wearing surfaces.

We will now describe the mode of ascertaining from the diagram the mean pressures on the opposite sides of the piston, in condensing and in non-condensing engines. For this purpose, divide the diagram into any desired number of equal parts, by lines drawn perpendicular to the atmospheric line. Sometimes these divisions are made very numerous, but the usual practice is to make ten, which number is probably sufficient, unless great accuracy is desired, when twenty divisions may be made. A convenient instrument for facilitating this operation, saving time, and ensuring accuracy, is furnished with these indicators. It consists of a parallel ruler, of eleven bars of thin steel, and a small square. A perpendicular line is first drawn by the square at one end of the diagram, when, the outer edge of bar No. 1 being brought to this line, and the inner edge of bar No. 11 to the opposite end of the diagram, the dividing lines are drawn with a sharp-pointed pencil, or, on the metallic paper, with a common pin. If twenty divisions are desired, the intermediate lines for this purpose will also be readily drawn by means of this instrument, points being first marked in the middle of the outer divisions. It is an excellent practice to divide the diagram into equal divisions, also, by lines drawn parallel with the atmospheric line, each division representing a certain number of pounds pressure, generally five or ten, and the lines being numbered on the margin according to the scale of the indicator; by this means the engineer is able to observe much more accurately the general nature of the diagram. The same instrument may be employed for this purpose.

On diagrams from condensing engines, the line of perfect vacuum should be drawn at the bottom, and the line of the boiler pressure, as shown by the gauge, at the top. The line of perfect vacuum varies in its distance from the atmospheric line, or, more correctly, the latter varies in its distance from the former, according to the pressure of the atmosphere, as shown by the barometer, from 13·72 lbs. on the square inch when the mercury stands at 28 in., to 15 lbs. when it stands at 30·6 in., and it should be drawn according to the fact, if this can be ascertained. The pressure of the atmosphere is usually reckoned at 15 lbs., which is too high, being correct only when the barometer stands at 30·6 in., a most unusual occurrence; but the error is unimportant, and it is very convenient to avoid the use of a fraction, and to say that 30 lbs., 45 lbs., 60 lbs., so on, represent 2, 3, 4, 5, 6 atmospheres of pressure.

The principal object of knowing the exact pressure of the atmosphere is to ascertain the duty performed by the condenser and air-pump. The temperature of the discharge being known, the pressure of vapour inseparable from that temperature is also known, and this being deducted from the actual pressure of the atmosphere, the remainder is the total attainable vacuum at that temperature.

The areas of the diagram above and below the atmospheric line are usually calculated separately, to ascertain how effectually the resistance of the atmosphere is removed from the non-acting side of the piston, by those parts of the engine whose function this is. In case of engines working very expansively, however, the expansion curve crosses the atmospheric line, and sometimes at an early point of the stroke, as in diagram, Fig. 4213. In such cases, the whole space between the atmospheric line and the line of counter-pressure should be credited to the condenser and air-pump; not, of course, to be considered in estimating the power exerted, but for ascertaining the degree of economy in the consumption of steam, which depends greatly on the amount of vacuum maintained.

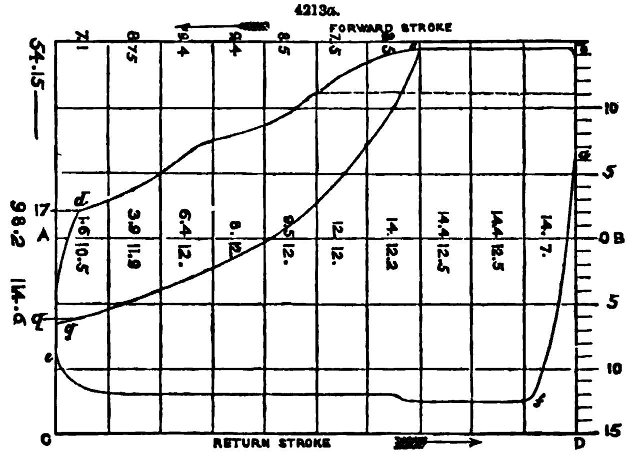
The lines having been accurately drawn as above directed, ascertain, by careful measurement with the scale, the mean pressure in each division, between the atmospheric line and the upper outline of the diagram, until this crosses the former, if it does so: add these together, and point off one place of decimals, or divide their sum by the number of divisions, if there are more than ten, and the quotient will be the mean pressure above the atmosphere during the stroke. Then repeat the process for the area between the atmospheric line, or the expansion curve after it has crossed this line, and the lower outline of the diagram. Add the two mean pressures so ascertained together, then find the number of square inches in the surface of the piston, if the diameter is known, and multiply the pressure on one square inch by the number of square inches, and the product by the mean velocity of the piston in feet a minute, and divide by 33,000, and the quotient will be the gross number of horse-powers exerted: or the power represented by the two areas of the diagram, above and below the atmospheric line, may be calculated separately.

The strictly accurate mode of measurement is, to measure the pressure of steam from the line

of perfect vacuum, when the line of 15 lbs. pressure will come a little above the atmospheric line, but it is more convenient, and answers all the purposes of the diagram better, to measure each way from the latter.

The space above the steam line and between this and the line of boiler pressure shows how much the pressure is reduced in the cylinder by throttling, or by the insufficient area of the ports, proper allowance being made for the difference of pressure necessary to give the required motion to the steam in the pipe; whilst the space between the line of counter-pressure and the line of perfect vacuum shows the amount of resistance to the motion of the piston.

4213a.



In illustration of the foregoing directions, let it be required to find the effective power exerted by the pair of engines, from the upper end of one of which the diagram, Fig. 4213a, was taken, the diameter of the cylinder being 95 in., the stroke of the piston 10 ft., and the number of revolutions 15 a minute. We will assume that the other engine would have given the same diagram, which is possibly correct, and also that the lower ends of the cylinders would have given the same, which is probably quite incorrect, because in side-lever or beam engines the speed of the piston at the lower end is slower, and therefore probably the pressure obtained is greater than in the upper end, the motion of the valves being the same.

The mean pressure of steam above the atmosphere was .. 98·2 ÷ 10 = 9·82 lbs.
The average vacuum was .. .. 114·6 ÷ 10 = 11·46 „

Total excess of pressure above the resistance was .. .. 21·28 „

The better mode of calculation in all cases is to obtain first the number of horse-powers for 1 lb. of mean pressure on the square inch as follows;—

No. of square inches in the surface of the piston .. .. .. 7088·2
Speed of the piston in feet a minute, 15 × 20 = ... 300

21264600

21264600 ÷ 33000 = 64·44

No. of horse-powers exerted for each pound of pressure during the stroke on 1 sq. in. of the piston .. .. 64·44
To obtain the gross power we multiply this by .. .. 21·28

Then the gross horse-powers exerted in one engine .. .. 1371·2832

To obtain the effective power, we must subtract from the multiplier .. .. 21·28 lbs.
The pressure required to run the engine alone, which in so large an engine would probably not exceed .. 1·00 lb.
And the increase in this pressure required to overcome the increased friction when the resistance is being overcome, say 5 per cent. .. .. = 1·06 „
2·06 „

Effective pressure on each square inch .. .. 19·22 „
Which multiplied by .. .. 64·44 „ = 1238·5368

Given amount of effective horse-power .. .. 1238·5368
Which multiplied by 2

Gives .. .. 2477·0 horse-power
as the effective power of the pair of engines.

It will be observed that, by the above mode of calculation, we obtain for any engine, the speed of piston continuing the same, a constant number, which, multiplied by the mean pressure on a square inch, gives at once the amount of horse-power exerted at any time.

On diagrams from non-condensing engines, the line of boiler pressure should be drawn at the top, and it is well to draw the line of perfect vacuum also, that the engineer may be able to see at a glance the quantity of steam consumed, and to compare with it the amount of work done. It is not possible that the back pressure resisting the motion of the piston shall be less than the pressure of the atmosphere, but it may be a great deal more, and very commonly in non-condensing engines the line of

resistance is as much as 2 or 3 lbs. above the atmospheric line, though it is quite possible to avoid this excess altogether.

The mean pressure is ascertained in the manner already directed for obtaining the pressure above the atmospheric line in condensing engines, and the power is calculated in the same way.

In the same manner, on stationary engines, the power shown by the frictional diagrams can be calculated, and also the various powers shown by diagrams taken when the shafting only is being driven, and when greater or lesser proportions of the whole resistance are being overcome; whilst on vessels the effects of different depths of immersion can be determined.

So also the power required in non-condensing engines to overcome the resistance of the atmosphere is readily ascertained.

It often happens, in non-condensing engines working expansively, that the expansion curve falls below the atmospheric line. In such cases the enclosed area below the atmospheric line must be deducted from that above this line to give the power really exerted.

Generally, engines will give the same figure at each revolution, the pencil retracing the same line so long as the resistance continues the same; but sometimes this is not the case. In such cases, care must be taken to obtain the average diagram. Also, in comparing the pressures required to overcome different resistances, it is essential that the speed of the engine in each case be the same—a requirement often disregarded.

Amount of Steam consumed.—For this purpose, draw the line of perfect vacuum, if not precisely known, at 14·7 lbs. below the atmospheric line. Ascertain how much the clearance and the thoroughfare at one end of the cylinder adds to its length, as represented by the stroke of the piston, and add a proportionate quantity to the length of the diagram by a line drawn perpendicular to the atmospheric line, at the proper distance from the admission line. Then ascertain the point in the stroke at which the steam is released, and the pressure in the cylinder at that point. Multiply this pressure, reckoned from the line of perfect vacuum, and which must be taken before the exhaust-port has been opened, by the sectional area of the cylinder in square inches, and the product by the length of the stroke in inches, up to the point at which the steam was released, and including the addition for the clearance and thoroughfare; then divide by 14·7, and the quotient will be the number of cubic inches of steam, at the pressure of the atmosphere, discharged from the cylinder at a single stroke. Multiply this by the number of strokes in an hour, and divide the product by 1728 to reduce the cubic inches to cubic feet, and the quotient again by 1700, to reduce the steam at atmospheric pressure to water, and the result will be the number of cubic feet of water used an hour; multiply this by 62·38 for pounds, and divide the product by 10 for gallons.

In case the steam is worked expansively, there are two points to be noted. First, that the density or pressure of the steam at the point of release is always greater, and commonly very much greater, than it ought to be, in order to account for the quantity of steam at the point of cut-off, the excess being caused by the evaporation of water in the cylinder during the expansion, which water must instantly burst into steam as the pressure falls below that due to its temperature, provided the heat of evaporation can be obtained from the metal; and, second, that generally even that quantity of steam increased in this manner will not account for all the water supplied to the boiler, showing that the chilling of the cylinder during the expansion, down to the temperature of the steam when released, was insufficient to supply heat to evaporate all the water it contained.

We are able, by means of the diagram, first to compare the quantity of steam consumed, measured as above directed, with the amount of power exerted; second, to ascertain the quantity of water evaporated in the cylinder during the expansion; and, third, to compare the steam appearing in the cylinder with the water evaporated in the boiler, or supposed to have been so: for, in fact, we know very little about the proportions of steam and water in the mixture which the boiler supplies. The field here presented is one of the most important in which the indicator can be employed. Different engines, and different boilers with the same engine, are found to give results, in all the above respects, differing most widely from each other.

Vibrations of the Spring.—Sometimes at very high speeds, or with very sudden action of the steam, the spring of the indicator is put into vibration. If the line produced by these vibrations is a waving line quite free from angles, this is an evidence that the action of the instrument is nearly frictionless, and the mean of the vibrations gives the true line.

Diagrams from the Valve-chamber.—These ought always to be taken when it is desired to know about the sufficiency of the ports or valve movements. It is obvious that for this purpose it is necessary to compare the pressure got in the cylinder with that in the valve-chamber. This also shows the sufficiency or insufficiency of the steam-pipes.

See Boilers. Planimeter. And also 'Description of Richards' Steam-Engine Indicator,' by Charles T. Porter, 8vo, 1868; and 'The Indicator Diagram Practically Considered,' by N. P. Burgh, crown 8vo, 1871.

INERTIA. Fr., *Inertie*; Ger., *Tragheit*; Ital., *Inerzia*; Span., *Inércia*.

Inertia is a quality possessed by all bodies, and is of the utmost importance in mechanical investigations. It may be defined as the tendency of matter to persist in its actual state, whether of motion or of rest. That matter should be incapable of spontaneous change is credible enough, since it is one of the most universal results of human observation, and is equivalent to stating that mere matter is destitute of life; for spontaneous action is the test of the presence of the living principle. Yet the fact, as stated in the above definition, seems at first sight to be in part opposed to the teaching of daily experience. We see that all motion is communicated, and that it comes to an end. The ball set rolling sooner or later stops, and we are led to infer that rest is the normal state of things, and that everything has a tendency to return to its normal state. This is an illusion, however, which reflection quickly dissipates, and we find it impossible to conceive how a body once set in motion can of itself arrest that motion. But it is not strictly true, as some writers affirm, that inertia implies absolute passiveness; for bodies *resist* a change of state. A body at rest resists motion, and a body in motion resists the force which tends to bring it to rest.

Beyond this, however, it is perfectly indifferent to rest or motion. Unnumbered instances daily and hourly fall under our observation of the utter inability of inorganic matter at rest to put itself in motion; but we have not like instances of its inability when in motion to bring itself to rest, since every terrestrial thing sooner or later does come to rest. But if we consider the fact that a ball set rolling upon rough ground quickly stops; that the same ball set rolling with the same initial velocity upon a smooth floor continues its motion much longer, and upon perfectly smooth ice longer still, we are forced to conclude that the motion is destroyed by external causes, as friction, resistance of the air, and gravity, and that if these causes were wholly removed as they have been removed in part, the ball would roll on in a straight line for ever. And that such would be the case is shown by the heavenly bodies, which are not exposed to these retarding influences. These, retaining the same force which was communicated to them "in the beginning," continue to move with a uniform velocity.

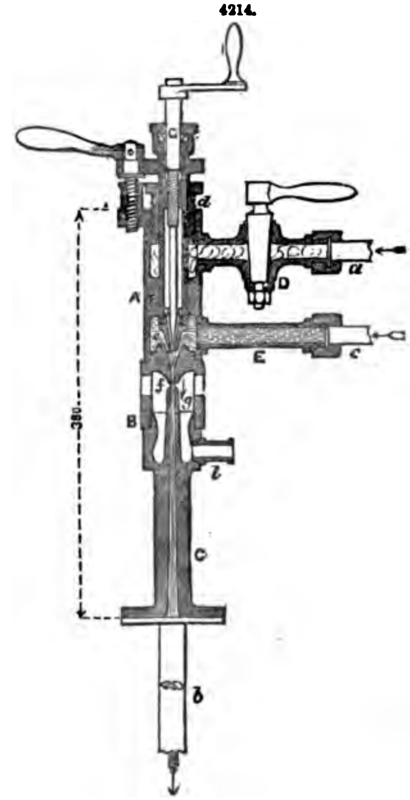
Of the numerous effects of inertia, we may instance that produced on a man on horseback by the sudden starting or stopping of the horse. If the horse start suddenly forward from a state of rest, the rider, whose body resists the motion, is thrown backward. If the horse when in rapid motion suddenly stops, the rider, whose body in this case resists the change from motion to rest, is thrown forward. Of similar effects produced by this property of inertia, our daily experience furnishes us with innumerable instances.

INJECTOR. Fr., *Injecteur;* Ger., *Injector;* Ital., *Iniettore;* Span., *Inyector.*

An injector is an apparatus frequently employed for feeding boilers with water, and other similar purposes.

Fig. 4214 is of one of Giffard's injectors, of French manufacture. A B C is the body of the apparatus, made in three pieces and screwed together by suitable connections. The upper piece A has a cock D, to which is fixed a tube *a*, communicating with the boiler, and through which steam is admitted. E is the water-branch fastened to a pipe *c*, communicating with the feed-water tank. Steam is first admitted from the boiler through the pipe *a*, and the amount is regulated by the conical spindle G, which fits into the steam-cone *e*. The water drawn through the supply-pipe E by the steam-jet rushing out of the cone *e* into the combining cone *f*, meets with the prime mover, the steam, which imparts a certain amount of its momentum to the water, and this stream consisting of water, condensed water, and steam, in its turn rushes across the small space between the combining and receiving cone *g*, through which it is forced by its superior velocity into the boiler through a pipe *b*, Fig. 4214.

4214.



In the experience of the working of Giffard's injector for the supply of water to steam-boilers, which has now come so extensively into use both in this country and abroad, various requirements have been found to arise; and for the purpose of meeting these, several improvements of the instrument have been introduced, one of the most remarkable of which, writes John Robinson in the Transactions I. M. E., is an arrangement invented by William Sellers, of Philadelphia, to obviate the necessity of adjusting by hand the quantity of water supplied to the injector, and thus render the instrument to that extent self-adjusting.

In the original Giffard's injector, shown in Fig. 4215, the quantity of water allowed to reach the combining cone B is adjusted by means of the external regulating hand-screw F, which by raising or depressing the steam-cone A increases or diminishes the annular opening for water. In Sellers' self-adjusting injector this opening is adjusted by the application of a piston in a cylinder, actuated by the amount of pressure or of vacuum existing alternately in the overflow-chamber, according as the supply of water is in excess or deficient.

The construction of the self-adjusting injector is shown in the vertical section, Fig. 4216. The steam-cone and the combining cone are arranged within the receiving cone; and the admission of steam through the steam-cone is regulated as hitherto by the handle D of the steam-spindle. The combining cone at its base is so made as to form a piston, which separates the water-chamber G from the overflow-chamber. The interval, a section of which is shown enlarged, forms the entrance to the receiving cone, and also to the overflow-chamber. The boiler-valve H prevents the water returning from the boiler; and K is a waste-cock, which when open allows the water and steam to issue into the atmosphere.

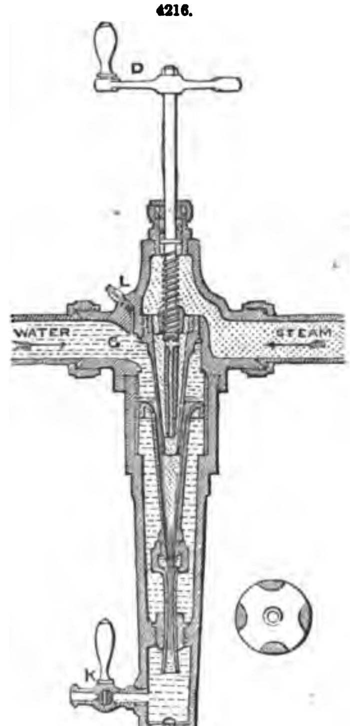
The mode of working the instrument is as follows;—The waste-cock K being first opened, the supply of water admitted from the tank is allowed to flow out through the waste; and the steam being then turned on by the handle D, an immediate increase takes place in the volume of water escaping at the waste-cock, showing that the jet has been established. The waste-cock is then closed, and the water flows into the boiler through the valve H. In case there should be too

much water admitted to the combining cone, the superabundance will be driven into the overflow-chamber below the piston, and will raise the piston so as to diminish the annular space between the combining cone and the steam-cone, and thus reduce the water supply until the quantity admitted is in exact proportion to the supply of steam. The relative positions of these cones will then remain the same until some change takes place in the pressure of the steam. Supposing the pressure of the steam in the boiler should increase, so that a larger quantity of steam is discharged through the steam-cone, the increased velocity of the jet will carry along with it into the boiler some of the water which had previously escaped through the openings in the interval into the overflow-chamber, and will thus produce a partial vacuum under the piston; the pressure of the water will then cause the piston to recede from the steam-cone and admit more water, until the proper proportion is again established. At the junction of the water-branch G with the main body of the injector a small valve L is provided, opening outwards; and the escape of steam from this valve gives warning that the injector has ceased working from want of water, similarly to the escape of steam from the overflow-pipe M in the original injector, Fig. 4215.

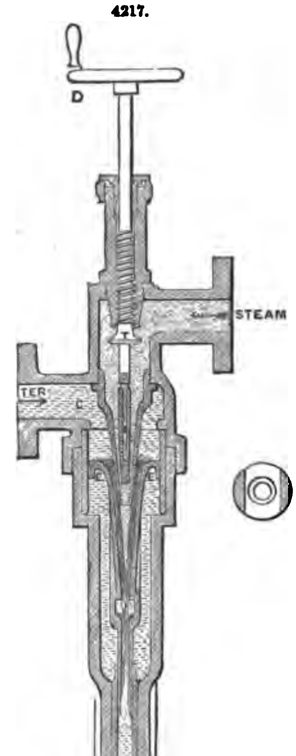
In many boilers, such as those having a small water and steam capacity compared with their heating surface, and where the demand for steam is very irregular, the variations in the steam-pressure are considerable and frequent, and the amount of attention required for regulating an ordinary injector becomes somewhat inconvenient; under such circumstances the ingenious and simple arrangement now described for rendering the injector self-adjusting will be found extremely useful. It is evident that this arrangement of injector does not permit any overflow to take place after the injector is once started. Also, as no air can get admission to the receiving cone of the injector, in consequence of there being no open overflow pipe, the entering water-jet is not impeded in its progress by the contact of air tending to enter with it. In injectors having an open overflow, air can gain access to the entering water-jet, and the quantity of water passing into the boiler is consequently diminished.

An arrangement for rendering the self-adjusting injector also self-starting has been contrived at J. Robinson's works, in order to obviate the necessity for opening and closing by hand the waste-cock K, Fig. 4216. In the improved injector, shown in Fig. 4217, the spindle of the boiler-valve H carries a smaller conical valve S, which, when the injector is not at work, is always kept open by the pressure of the boiler upon the valve H. When therefore the steam is turned on for starting the injector, the water is first allowed by the valve S to escape through the waste-pipe Q; but as soon as the jet is established, the valve H opens to the boiler, and at the same time closes the conical valve S, and stops the escape through the waste-pipe. This arrangement has the advantage not only of rendering unnecessary the opening and closing by hand of the waste-cock, but also of showing very clearly when the injector ceases working; because when that happens the boiler-valve H is closed by the back pressure from the boiler, opening simultaneously the valve S and allowing the steam and water to escape through the waste-pipe Q.

4216.



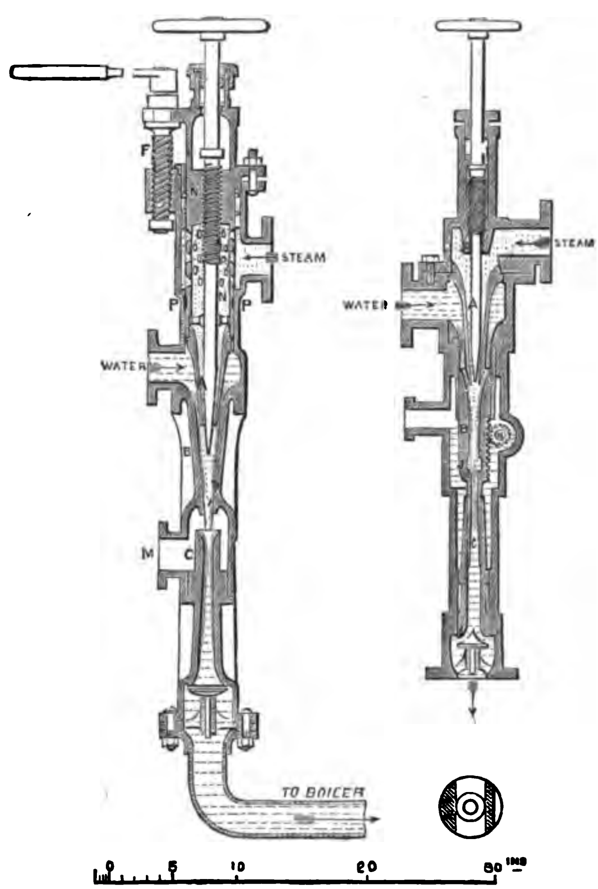
4217.



In Fig. 4218 is shown the improved arrangement of the ordinary injector with hand adjustment, designed by Robinson and Gresham, which has now come into extensive use in place of the original

form of injector. In the original injector, shown in Fig. 4215, the combining cone B and receiving cone C are stationary, and the admission of water is regulated by sliding longitudinally the steam-cone A, which is carried upon the extremity of a hollow cylinder N, passing through a stuffing box at the top of the instrument, and requiring also an internal ring of packing at P, in order to prevent the steam from blowing through into the water-chamber. With high-pressure steam, such as 120 lbs., having a temperature of 350° Fahr., this internal packing becomes injured by the constant exposure to the high temperature whilst working, and involves the trouble of frequent renewal; and in order to obviate this difficulty, the improved injector, shown in Fig. 4218, is constructed with the converse arrangement of the cones, the steam-cone A being made a fixture in the instrument, while the combining cone B and receiving cone C are cast together in a single piece, sliding longitudinally, and are moved by the internal rack and pinion R. By this means the necessity for any internal packing is avoided, as no internal steam-tight joint is required; and at the same time the stuffing box at the top of the sliding cylinder N, Fig. 4215, is also done away with. The sliding cones B and C, Fig. 4218, require only to be turned originally to an easy fit in their external cylindrical guides, as it is not necessary for these joints to be absolutely water-tight. The only additional requirement involved in this arrangement is the stuffing box for the spindle of the pinion R, which is packed externally and has only to be made water-tight, in contrast with the internal steam-tight packing P in the original injector, Fig. 4216.

4215. 4218.

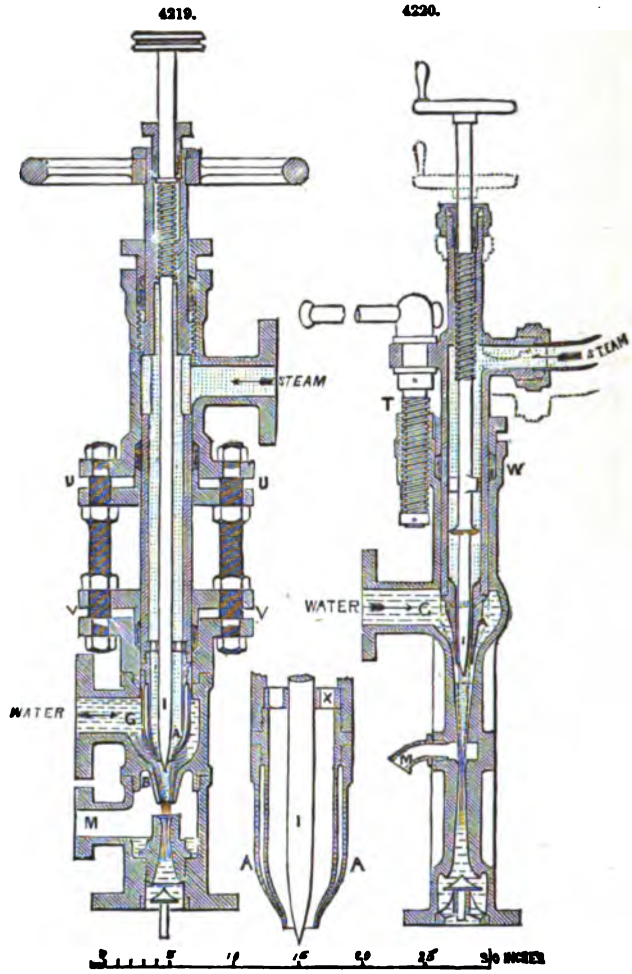


There appears to be a possible drawback to the application of these self-adjusting injectors in cases where a high temperature of supply water is to be used, and especially where that temperature varies, as in the case of a locomotive engine. This drawback consists in the probability that under such circumstances the injector might be difficult to start, because there is no open overflow pipe for allowing the surplus water to escape, and therefore a greater quantity of water cannot be used to condense the steam-jet than can be admitted into the boiler in a given time through the receiving cone of the injector. With the ordinary open overflow, however, a larger quantity of water than can obtain access to the boiler may be admitted to condense the steam current, the surplus escaping at the overflow; and thus a feed can be established, although overflow may at the same time take place.

Endeavours have been made by Andrew Barclay, of Kilmarnock, and others to construct an ordinary Giffard's injector in such a manner that it will draw water from a considerable depth; and this has been successfully accomplished to the extent of lifting the water from a depth of 15 or 18 ft. below the water-chamber of the injector, the temperature of the supply water being 60° Fahr. The construction of injector employed for this purpose is shown in Fig. 4219, and the success is attributable to the care taken to obtain a better vacuum in the water-chamber G by means of double stuffing boxes U and V. One of these, U, prevents the escape of steam into the air, and the other, V, prevents the entrance of air into the water-chamber G. Considerable importance is also attached to the advantage of a shielded steam-cone A, shown to a larger scale, the extremity of the cone being surrounded by an external casing, leaving an air space between of ¼ in. width closed at the bottom, which serves as a non-conductor to prevent the steam from being cooled and cause it to preserve its full heat to the very extremity of the steam-nozzle. The steam-adjusting spindle I is also made to project through the steam-cone A into the combining cone B in the same way as in the original injector, Fig. 4215, so as to secure not only an annular steam-jet but also an annular combined jet; and the spindle is steadied near the extremity by the guide X, to keep it truly central with the jet.

Another arrangement of injector for the same object is shown in Fig. 4220, where the sliding steam-nozzle has only a single stuffing box W, which prevents the ingress of air to the water-chamber; the steam entrance is fixed upon the sliding steam-nozzle, and moves with it, so as to preclude the necessity for a second stuffing box to prevent leakage of steam. This construction requires, however, a flexible steam-pipe, in order to allow for the motion of the sliding steam-nozzle. When the injector is used for lifting water from a lower level, the steam-cone A is first turned down by the regulating screw F to its extreme lowest position, as shown by the dotted lines, leaving a small annular passage for water between the steam-cone and the combining cone. The steam-spindle I is then turned once round, which gives sufficient opening for the amount of steam required to exhaust the water-chamber G. As soon as the water is seen to issue from the overflow-pipe M, the handle F is turned so as to raise the steam-cone A to a position suited to the pressure in the boiler, and the steam-spindle I is drawn back until the overflow ceases.

4219. 4220.



INSULATOR. Fr., *Isoloir;* Ger., *Isolator;* Ital., *Isolatore;* Span., *Aislador.*

In Electricity or Thermotics, an insulator is any body or substance that insulates or acts as a non-conductor.

In Telegraphy, when a wire is suspended on poles, it is fixed to *insulators* to prevent the escape of the current at the points of support; when it is carried underground, through wet tunnels or through water, the insulation must be continuous, and the wire is covered with gutta-percha or india-rubber. See Telegraphy.

IRON. Fr., *Fer;* Ger., *Eisen;* Ital., *Ferro;* Span., *Hierro. y fierro.*

There are two distinct varieties of iron; one is a fibrous metal, or wrought iron; and the other, a granulated or crystallized metal, cast-iron or steel. These varieties of iron are subdivided, as we shall explain hereafter. All iron of commerce is impure; in fact, a pure article would not serve the uses to which iron is commonly applied. Pure iron is silver-white, of a very agreeable, mild, and at the same time brilliant lustre, and of a fibrous fracture. It assumes a high polish, particularly when rubbed with a hard, well-polished substance. Iron is easily tarnished; it has great affinity for oxygen, and acids dissolve it rapidly. Alkalies, in whatever form they may be, protect it remarkably well against corrosion; its sp. gr. is 7·78. It is the most tenacious of the metals, very soft when pure, but becomes extremely hard when alloyed with other metals, or any substance which combines chemically with it. It is singularly affected by magnetic currents; no other metal is more sensitive to that force than iron. Its susceptibility for oxygen, or it may be another cause, imparts a disagreeable taste to pure iron, when applied to the tongue. It also emits a peculiar smell when strongly rubbed. Iron has so great an affinity for other matter, that its existence in a pure condition is very doubtful; at least that presented by chemists, and obtained by them from wire-scraps, filings, hammer-scales, or similar means, cannot be pure. A means of obtaining pure iron is to reduce pure oxide of iron in a glass tube by means of hydrogen; but the iron thus obtained is in the form of a fine powder, and oxidizes when exposed to atmospheric air. When the heat in this operation is raised to redness on the oxide, before hydrogen is applied, the metal agglutinates into a grey porous mass, which is not much affected by cold atmospheric air. It was until recently supposed that pure iron could be obtained by the

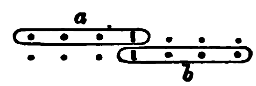
galvano-plastic process, described at p. 1382, and of which particular mention is made by Dr. Percy in his work on Iron and Steel. All experiments which have been made to obtain it are indicative of its being infusible when freed from foreign matter; the degree of heat at which it is fused increases with its degree of purity. In practice we have impure iron exclusively, and all our investigations are confined to alloys of iron.

Our Chemical Knowledge of Iron.—Iron undergoes no alteration either in oxygen or in dry air. But in moist air it becomes oxidized and covered with rust; the presence of carbonic anhydride facilitates this change. The oxidation takes place at the expense of the water, and the hydrogen liberated unites with the nitrogen of the air, forming ammonia, with which rust is always impregnated.

Iron decomposes water when at a red heat by liberating the hydrogen. At this temperature it also unites directly with the atmospheric oxygen; it then forms an oxide which has been called crust-oxide, because it forms the flakes or crust which are detached from the hot metal when hammered; this crust is also known as iron-scale or hammer-slag. When cold, iron is dissolved in acids with a setting free of hydrogen.

Iron forms, with the monatomic radicals, two series of compounds; into the former of these a single atom of this metal enters, which in this case is never saturated. To these compounds correspond others of the same order, which iron generates by uniting with he diatomic radicals. All the compounds of this order bear the name of minimum combinations, or ferrous compounds.

Besides these combinations, iron forms others, containing not a single atom of this metal, but the group Fe^2. This group is naturally hexatomic, since the two atoms of iron mutually exchange an atomicity or capacity of saturation. This is shown by the annexed figure, in which *a* and *b* represent two atoms of tetratomic iron, giving rise to the group Fe^2, in which we find only six free attractive centres instead of eight. The group Fe^2 is therefore susceptible of either, with six monatomic radicals, or with three diatomic radicals. The compounds of this order are usually known by the name of maximum or ferric compounds.



The principal compounds of iron are the following;—

Minimum or ferrous compounds.		Maximum or ferric compounds.	
Protochloride of iron	$FeCl^2$	Perchloride of iron	Fe^2Cl^6
Protobromide..	$FeBr^2$	Perbromide	Fe^2Br^6
Protoiodide	FeI^2	Periodide	Fe^2I^6
Protofluoride	$FeFl^2$	Perfluoride	Fe^2Fl^6
Hydride	FeH^2	Sesquioxide	$Fe^2\Theta^3$
Protoxide	$Fe\Theta$	Sesquisulphide	Fe^2S^3
Protosulphide	FeS	Maximum hydrate of iron ..	$\left.\begin{matrix}Fe^2\\H^6\end{matrix}\right\}\Theta^6$
Minimum salts	$\left.\begin{matrix}Fe\\(R')^2\end{matrix}\right\}\Theta^2$	Various maximum salts	$\left.\begin{matrix}Fe^2\\(R')^6\end{matrix}\right\}\Theta^6$

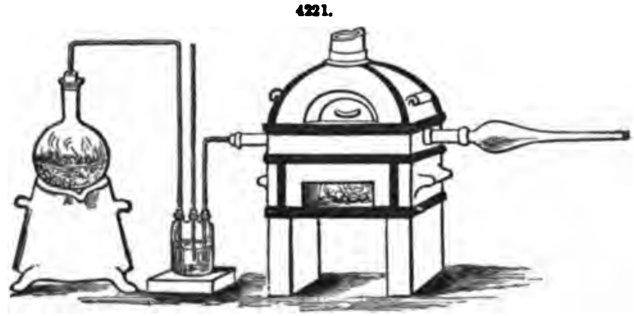
R′ is a monatomic acid radical.

In virtue of the property which the diatomic radicals have of accumulating in the molecules, sulphur and oxygen form with iron, besides the preceding compounds;—

Magnetic oxide of iron	$Fe^3\Theta^4$
Ferric anhydride	$Fe\Theta^3$
Bisulphide of iron	FeS^2
Magnetic pyrite	Fe^7S^8

Ferrous Compounds of Iron.—Protochloride of Iron, $Fe''Cl^2$.—Anhydrous protochloride of iron is obtained by causing a dry current of hydrochloric acid gas to pass through a porcelain tube, Fig. 4221, containing pure iron, at a red heat.

4221.



$$\underset{\text{Iron.}}{Fe} + \underset{\text{Hydrochloric acid.}}{2\left(\left.\begin{matrix}H\\Cl\end{matrix}\right\}\right)} = \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}} + \underset{\text{Protochloride of iron.}}{Fe''Cl^2}$$

This salt is condensed in bright scales upon the walls of the cold portion of the tube. Ferrous chloride is volatile and soluble in water and alcohol. Its aqueous solution is of a green

colour. When evaporated, it leaves a deposit of green hydrated crystals, the formula of which is $Fe\,Cl^2 + 4\,aq.$ Exposed to the air, this solution absorbs oxygen and loses its transparency; its colour then becomes yellowish, and in this case a chloroxide $Fe^2\,Cl^4\,\Theta$ is formed.

$$\underset{\text{Protochloride of iron.}}{4\,Fe''\,Cl^2} + \underset{\text{Oxygen.}}{\left.\begin{matrix}\Theta\\\Theta\end{matrix}\right\}} = \underset{\text{Chloroxide of iron.}}{2\,Fe^2\,Cl^4\,\Theta}$$

If an acid and an oxiding body be made to act simultaneously upon protochloride of iron, a double maximum salt is formed

$$\underset{\text{Protochloride of iron.}}{4\,Fe\,Cl^2} + \underset{\text{Oxygen.}}{\left.\begin{matrix}\Theta\\\Theta\end{matrix}\right\}} + \underset{\text{Nitric acid.}}{4\left(\left.\begin{matrix}Az\,\Theta^2\\H\end{matrix}\right\}\Theta\right)} = \underset{\text{Tetrachloro-diazotate of iron.}}{2\left(Fe^{iv2}\left\{\begin{matrix}\Theta\,Az\,\Theta^2\\\Theta\,Az\,\Theta^2\\Cl^4\end{matrix}\right.\right)} + \underset{\text{Water.}}{2\left(\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta\right)}$$

Chlorine combines with ferrous chloride, and transforms it into ferric chloride

$$\underset{\text{Ferrous chloride.}}{2\,Fe''\,Cl^2} + \underset{\text{Chlorine}}{\left.\begin{matrix}Cl\\Cl\end{matrix}\right\}} = \underset{\text{Ferric chloride.}}{Fe^2\,Cl^6}$$

Protobromide of Iron, $Fe\,Br^2$.—The properties and mode of preparation of this substance being the same as those of the préceding body, it is useless to describe them.

Protoiodide of Iron, $Fe\,I^2$.—Hydrated protoiodide of iron is prepared for medical use by triturating in water 56 parts of iron with 254 parts of iodine; it is better to put a greater quantity of iron than 56 to give an excess of the metal. When the liquid has lost all smell of iodine, it is filtered and rapidly evaporated. The concentrated liquid gives up as it cools green crystals of iodide of iron. Contact with the air must be avoided as much as possible during the operation; for ferrous iodide changes quickly when exposed to the air by absorbing oxygen.

Protoxide of Iron, $Fe\,\Theta$.—If equal volumes of carbonic anhydride and oxide of carbon are made to pass upon sesquioxide of iron at a red heat, the iron is brought into the state of a protoxide. This substance always contains, however, a small quantity of the sesquioxide. A hydrate of iron may be obtained by precipitating a ferrous salt by potash.

$$\underset{\text{Protochloride of iron.}}{Fe''\,Cl^2} + \underset{\text{Potash.}}{2\,K\,\Theta\,H} = \underset{\text{Chloride of potassium.}}{2\,K\,Cl} + \underset{\text{Ferrous hydrate.}}{Fe''\left\{\begin{matrix}\Theta\,H\\\Theta\,H\end{matrix}\right.}$$

This hydrate is so liable to change, that it is impossible to dishydrate it without destroying it. Ferrous hydrate is green at the moment of its precipitation, but it quickly turns yellow on exposure to the air, by transforming itself into magnetic oxide.

$$\underset{\text{Ferrous hydrate.}}{6\left(\left.Fe''\right\}\begin{matrix}\Theta\,H\\\Theta\,H\end{matrix}\right)} + \underset{\text{Oxygen.}}{\left.\begin{matrix}\Theta\\\Theta\end{matrix}\right\}} = \underset{\text{Water.}}{6\left(\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Magnetic oxide.}}{2\,Fe^3\,\Theta^4}$$

Hydrate of iron is a true base susceptible of exchanging its oxhydride for the halogenic residue of the acids.

Protosulphide of Iron, $Fe\,S$.—This substance may be prepared either in the wet way, by precipitating a ferrous salt with sulphide of ammonium, or in the dry way, by heating a compound, made in atomic proportion, of sulphur and iron.

$$1.\quad \underset{\text{Protochloride of iron.}}{Fe''\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.} + \underset{\text{Sulphide of ammonium.}}{\left.\begin{matrix}Az\,H^4\\Az\,H^4\end{matrix}\right\}S} = \underset{\text{Chloride of ammonium}}{2\left(\left.\begin{matrix}Az\,H^4\\Cl\end{matrix}\right\}\right)} + \underset{\text{Protosulphide of iron.}}{Fe''\,S}$$

$$2.\quad \underset{\text{Iron.}}{2\,Fe} + \underset{\text{Sulphur.}}{\left.\begin{matrix}S\\S\end{matrix}\right\}} = \underset{\text{Protosulphide of iron.}}{2\,Fe''\,S}$$

Sulphide prepared by the wet way is pulverulent, black, and absorbs oxygen with extreme readiness in passing into the state of a sulphate. Sulphide obtained by the dry way is hard, brittle, and possesses a metallic lustre.

$$\underset{\text{Protosulphide of iron.}}{Fe\,S} + \underset{\text{Sulphuric acid.}}{\left.\begin{matrix}S\,\Theta^{2''}\\H^2\end{matrix}\right\}\Theta^2} = \underset{\text{Ferrous sulphate.}}{\left.\begin{matrix}S\,\Theta^{2''}\\Fe''\end{matrix}\right\}\Theta} + \underset{\text{Hydrosulphuric acid.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}S}$$

Steel dust and flowers of sulphur mixed and moistened react upon each other after a certain time; the reaction is accompanied by a great emission of heat. If the compound be buried a little distance beneath the surface of the earth in sufficient quantity, the aqueous vapours which become disengaged throw the earth to a considerable distance, and sometimes the combination is accompanied with an emission of light.

Ferrous Sulphate, $\left.\begin{matrix}S\,\Theta^{2''}\\Fe''\end{matrix}\right\}\Theta^2 + 7\,aq.$—In laboratories, this salt is prepared by dissolving iron in diluted sulphuric acid, concentrating the liquid by boiling, and then leaving it to cool, that the

salt may be deposited in crystals. For manufacturing purposes, this substance is prepared by roasting natural pyrites (bisulphide of iron).

$$\underset{\text{Pyrite.}}{\mathrm{Fe\,S^2}} + \underset{\text{Oxygen.}}{3\left(\begin{matrix}\Theta\\ \Theta\end{matrix}\right\}\Big)} = \underset{\text{Sulphurous anhydride.}}{\mathrm{S\,O^2}} + \underset{\text{Ferrous sulphate.}}{\mathrm{S\,Fe\,\Theta''}}$$

A washing is necessary after the roasting, and the liquid is left to clear. It is then decanted, and after sufficient evaporation, it is left to crystallize.

Certain pyrites absorb oxygen by merely being exposed to the air, without being heated. Sulphate of iron thus prepared contains many impurities, amongst others copper. As this latter metal might be injurious in certain cases, it is eliminated by placing for a short time strips of iron in the solution of sulphate; the iron substitutes itself for the copper, and the latter is precipitated.

Sulphate of iron is known in commerce under the name of green vitriol or green copperas.

Ferrous sulphate crystallizes in oblique rhomboidal prisms, of a greenish colour, and containing seven molecules of water. Its taste is astringent. One part of this salt requires to dissolve it 1·42 of water at 15° C. and 0·33 of boiling water. It is insoluble in alcohol, but this liquid deprives it of six molecules of water. It also loses $\frac{6}{7}$ of its water of crystallization when heated to 100° C., but it does not become perfectly anhydrous till 300° C. are reached. When calcined, ferrous sulphate is decomposed into sulphurous anhydride, sesquioxide of iron, and sulphuric anhydride. It may be remarked here that the preparation of the sulphuric acid of Saxony is founded upon this reaction.

$$\underset{\text{Ferrous sulphate.}}{2\left(\begin{matrix}\mathrm{S\,\Theta^{2''}}\\ \mathrm{Fe''}\end{matrix}\right\}\Theta^2\Big)} = \underset{\text{Sulphurous anhydride.}}{\mathrm{S\,\Theta^2}} + \underset{\text{Sulphuric anhydride.}}{\mathrm{S\,\Theta^3}} + \underset{\text{Sesquioxide of iron.}}{\mathrm{Fe^2\,\Theta^3}}$$

When exposed to the air, the crystals or the solution of ferrous sulphate absorb oxygen, and give a yellowish ferric subsulphate which may be destroyed by boiling it with iron. The minimum sulphate of iron, in an aqueous solution, will preserve its state only if the water in which it has been dissolved has been previously deprived of air by boiling, and the solution carefully protected from contact with the air.

Sulphate of iron crystallizes with seven molecules of water, and is isomorphous with the sulphates of the magnesian series.

Ferric or Maximum Compounds of Iron.—Perchloride of Iron, $\mathrm{Fe^2\,Cl^6}$.—Anhydrous perchloride of iron is obtained by causing an excess of chlorine to pass over iron heated to a red heat. The apparatus used for this purpose is the same as that employed in the preparation of ferrous chloride. This substance may also be prepared by distilling at a red heat in a stone retort hydrated perchloride prepared by the solution of iron in aqua regia. In the latter case, however, a portion of the perchloride is decomposed by the water into hydrochloric acid and sesquioxide of iron.

$$\underset{\text{Perchloride of iron.}}{\mathrm{Fe^2\,Cl^6}} + \underset{\text{Water.}}{3\left(\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\Theta\Big)} = \underset{\text{Hydrochloric acid.}}{6\left(\begin{matrix}\mathrm{H}\\ \mathrm{Cl}\end{matrix}\right\}\Big)} + \underset{\text{Sesquioxide of iron.}}{\mathrm{Fe^2\,\Theta^3}}$$

Hydrated perchloride of iron may also be procured by dissolving maximum hydrate of iron in hydrochloric acid.

$$\underset{\text{Ferric hydrate.}}{\left.\begin{matrix}\mathrm{Fe^{2vi}}\\ \mathrm{H^6}\end{matrix}\right\}\Theta^6} + \underset{\text{Hydrochloric acid.}}{6\left(\begin{matrix}\mathrm{H}\\ \mathrm{Cl}\end{matrix}\right\}\Big)} = \underset{\text{Ferric chloride.}}{\mathrm{Fe^2\,Cl^6}} + \underset{\text{Water.}}{6\left(\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\Theta\Big)}$$

By evaporating the liquid, and leaving it to cool, we obtain rhomboëdrical forms of a beautiful yellow colour, answering to the formula $\mathrm{Fe^2\,Cl^6} + 6\,\mathrm{aq}$. Ferric chloride is of the colour of cantharides' wings. It is volatile; water, alcohol, and ether dissolve it; water causes it to pass into the state of a hydrated chloride. When subjected to the action of aqueous vapour in a heated tube, this substance gives crystallized sesquioxide of iron, identical with the *specular iron* found in a natural state.

Ferric chloride in an aqueous solution is employed in medicine as a hemostatic, on account of the property it possesses of coagulating albumen; it is taken internally as a remedy for hemorrhage.

Perbromide and Periodide of Iron.—These substances may be obtained by combining directly iron with bromine or iodine in excess. They are of no practical use.

Sesquioxide of Iron, $\mathrm{Fe^2\,\Theta^3}$.—In commerce, this substance (colcothar) is prepared by calcining ferrous sulphate; in laboratories it is preferably prepared by heating ferric hydrate. It is found in nature crystallized; and is then isomorphous with aluminum.

Sesquioxide of iron is a basic anhydride. Yet the weak acids do not dissolve it; strong and boiling acids alone attack it by transforming it into ferric salts.

Ferric Hydrate, $\left.\begin{matrix}\mathrm{Fe^{2vi}}\\ \mathrm{H^6}\end{matrix}\right\}\Theta$.—To the sesquioxide of iron corresponds a basic hydrate, ferric hydrate. This substance is usually prepared by the decomposition of a ferric compound soluble by means of ammonia. The precipitate which is formed must be collected on a filter and well washed.

$$\underset{\text{rchloride of iron.}}{\mathrm{Fe^{2vi}}\left\{\begin{matrix}\mathrm{Cl^3}\\ \mathrm{Cl^3}\end{matrix}\right.} + \underset{\text{Ammonic hydrate.}}{6\left(\begin{matrix}\mathrm{Az\,H^4}\\ \mathrm{H}\end{matrix}\right\}\Theta\Big)} = \underset{\text{Ammonic chloride.}}{6\left(\begin{matrix}\mathrm{Az\,H^4}\\ \mathrm{Cl}\end{matrix}\right\}\Big)} + \underset{\text{Ferric hydrate.}}{\mathrm{Fe^{2vi}}\left\{\begin{matrix}(\Theta\,\mathrm{H})^3\\ (\Theta\,\mathrm{H})^3\end{matrix}\right.}$$

Ferric hydrate is reduced by hydrogen still more easily than colcothar. The weakest acids dissolve it by giving rise to maximum salts. When it is calcined, it loses its water, and becomes anhydrous. At the moment when this transformation is effected, the mass becomes incandescent. When put in suspension in a concentrated alkaline solution, through which a current of chlorine is directed, ferric hydrate passes rapidly into the state of an alkaline ferrate. According to M. Péan de Saint-Gilles, if ferric hydrate is boiled for seven or eight hours, it loses much water and is converted into a condensed anhydride, whose formula is

$$\left.\begin{matrix} Fe^{2vi}\left\{\begin{matrix}\Theta H\\ \Theta\\ \hline \Theta\\ \Theta\end{matrix}\right. \\ Fe^{2vi}\left\{\begin{matrix}\Theta\\ \hline \Theta\\ \Theta H\end{matrix}\right.\end{matrix}\right\} = Fe^4 H^2 \Theta^7.$$

This new compound does not offer the phenomenon of incandescence when it is calcined, and it dissolves with as much difficulty as the anhydrous sesquioxide. Graham succeeded in obtaining a soluble variety of ferric hydrate by subjecting ferric acetate to dialysis. This soluble hydrate appears to be a product of condensation.

Maximum Salts of Iron.—These salts are obtained by dissolving ferric hydrate in various acids. They may also be prepared by dissolving ferrous salts in water, and peroxiding them by a current of chlorine or by nitric acid. In the latter case, if it is required to obtain a neuter salt, there must be added to the liquid a certain quantity of the acid whose elements the salt contains. With an equal quantity of metal, the maximum salts contain, indeed, a greater number of molecules of the electro-negative group than the minimum salts, since in these latter the atom of iron is only *biavalent*, whilst in the former the double atom Fe^2 is *hexavalent*.

The following equation shows clearly this necessity of adding an acid to the ferrous salt which it is required to peroxide.

$$\underset{\text{Ferrous sulphate.}}{2\left(\left.\begin{matrix}S\Theta^{2''}\\ Fe''\end{matrix}\right\}\Theta^2\right)} + \underset{\text{Sulphuric acid.}}{\left.\begin{matrix}SO^{2''}\\ H^2\end{matrix}\right\}\Theta^2} + \underset{\text{Oxygen.}}{\Theta} = \underset{\text{Water.}}{\left.\begin{matrix}H\\ H\end{matrix}\right\}\Theta} + \underset{\text{Neuter ferric sulphate.}}{\left.\begin{matrix}Fe^{2vi}\\ (S\Theta^{2''})^3\end{matrix}\right\}\Theta^6}$$

When a reducing agent is made to act upon the ferric salts, the latter are transformed into ferrous salts, and at the same time a molecule of acid is liberated.

$$\underset{\text{Ferric sulphate.}}{\left.\begin{matrix}Fe^{2vi}\\ (S\Theta^{2''})^3\end{matrix}\right\}\Theta^6} + \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\ H\end{matrix}\right\}} = \underset{\text{Ferrous sulphate.}}{2\left(\left.\begin{matrix}S\Theta^{2''}\\ Fe''\end{matrix}\right\}\Theta^2\right)} + \underset{\text{Sulphuric acid.}}{\left.\begin{matrix}S\Theta^{2''}\\ H^2\end{matrix}\right\}\Theta^2}$$

The reducing agents capable of producing this result are, among others, hydrosulphuric acid, hydrogen, and steel-dust. In the case of the hydrosulphuric acid, the reduction is effected cold, sulphur is deposited, and the sulphuric acid is liberated; in that of the steel-dust, on the contrary, the solution of the salt required to be reduced must be boiled with that substance. Instead of free sulphuric acid, only ferrous sulphate is then formed.

Magnetic Oxide of Iron, $Fe^3\Theta^4$.—This oxide is found in nature, where it forms an excellent iron ore. Natural loadstones are composed of it. It may be produced artificially by causing aqueous vapour (steam) to pass over iron heated to a red heat.

$$\underset{\text{Iron.}}{3Fe} + \underset{\text{Water.}}{4\left(\left.\begin{matrix}H\\ H\end{matrix}\right\}\Theta\right)} = \underset{\text{Magnetic oxide of iron.}}{Fe^3\Theta^4} + \underset{\text{Hydrogen.}}{4\left(\left.\begin{matrix}H\\ H\end{matrix}\right\}\right)}$$

It may also be prepared by precipitating, by means of ammonia, a mixture of protochloride and perchloride of iron containing quantities of each of these substances corresponding to the weight of their molecule. In this case it is important to pour the mixture drop by drop into a great excess of ammonia. If, on the contrary, the ammonia were poured into the mixture, the alkali not being everywhere in excess at the same time, ferric hydrate would first be precipitated, then ferrous hydrate, but no magnetic oxide. Magnetic oxide must be considered as a minimum salt of iron generated by the second anhydride of the maximum hydrate of the same metal acting as an acid.

$$\underset{\text{Ferric hydrate.}}{\left.\begin{matrix}Fe^2{}_{vi}\\ H^6\end{matrix}\right\}\Theta^6} - \underset{\text{Water.}}{2H^2\Theta} = \underset{\text{2nd anhydride of the maximum hydrate.}}{\left.\begin{matrix}Fe^2\\ H^2\end{matrix}\right\}\Theta^4} - \underset{\text{Hydrogen.}}{2H} + \underset{\text{Iron.}}{Fe''} = \underset{\text{Magnetic oxide of iron.}}{\left.\begin{matrix}Fe^{2vi}\\ Fe''\end{matrix}\right\}\Theta^4}$$

There exist, indeed, aluminates of iron isomorphous with it, which leave no doubt as to its true constitution.

Ferric anhydride, $F\Theta^3$.—Ferric anhydride is not known; but when we direct a current of chlorine through a concentrated alkaline solution holding ferric hydrate in suspension, there is formed a red salt which is none other than the ferrate of potash $FeK^2\Theta^4$, corresponding to the manganate of potash $MnK^2\Theta^4$.

Bisulphide of iron, FeS^2 (pyrites).—The pyrite represents a saturated minimum compound of iron. It is the only one known. It exists in nature, crystallized sometimes in cubes, sometimes in prisms. The cubic pyrite is the most common; it is hard enough to cut glass and to emit

sparks when struck with steel. Its density varies from 4·083 to 5·031 according to Dana, and from 5·0 to 5·2 according to Rammelsberg. It has a metallic appearance; acids do not change it; but it is readily affected by aqua regia. Sometimes this pyrite becomes oxidized when exposed to the air, sometimes it is inoxidable. The prismatic pyrite always becomes oxidated on exposure. When heated with carbon, bisulphide of iron gives sulphuret of carbon and protosulphuret of iron.

Magnetic pyrites, $Fe^7 S^8$.—This substance is found in nature crystallized into regular hexahedral prisms. It acts upon the magnet. Its composition is not very constant; it appears that these pyrites result from the combination of the other sulphurets among each other without our knowing exactly what the sulphurets are that are thus combined. They may be obtained artificially by heating a piece of iron to a white heat and plunging it into a crucible filled with molten sulphur: the pyrites collect at the bottom of the crucible.

Titanitic Iron.—There exists in a natural state a substance called titanitic iron, containing iron, titanium, and oxygen. This substance is isomorphous with the sesquioxide of natural iron. To explain this isomorphism, we are obliged to consider titanitic iron as a compound of sesquioxide of iron $Fe^2 \Theta^3$ and an oxide $Ti\,Fe\,\Theta^3$, which would be none other than the preceding oxide, in which an atom of titanium was substituted for an atom of iron. If this interpretation is the true one, the substitution of an atom of tetratomic titanium for an atom of iron, and the isomorphism of this product of substitution with the ordinary oxide of iron, furnish another proof of the *tetratomicity* of iron.

Character of the Salts of Iron.—The minimum salts are generally green, and the maximum salts yellowish, they are distinguished from each other by the following characteristics;—

1. Ferrocyanide of potassium precipitates the minimum salts of iron blue, and the maximum salts white.
2. Sesquiferrocyanate of potassa precipitates the minimum salts of iron blue, and does not precipitate the maximum salts.
3. The alkalies give with the minimum salts a green precipitate which turns yellow on exposure to the air, and with the maximum salts a yellow precipitate which does not change its colour.
4. Hydrosulphuric acid does not act upon the minimum salts; it reduces the maximum salts, with a deposit of sulphur.
5. The alkaline sulphurets give with both classes of salts a black precipitate very soluble in diluted acids.

Iron deposited galvanically.—The difficulty of obtaining chemically pure iron, for the purpose of studying its properties, led to the attempts to precipitate it from its solutions by galvanic action, which is easily done by employing a weak battery and a solution of sulphate of iron, mixed with sulphate of magnesia; having, at the same time, sufficient carbonate of magnesia in the solution to keep it constantly neutral in proportion as the iron is reduced. Thus obtained, the iron presents itself as a fine-grained deposit, in which no trace of crystallization can be seen under the microscope. Its colour is a soft light grey, and its hardness is so surprisingly great that it can only be scratched with a file; it being at the same time so brittle that a piece $\frac{1}{8}$ of an inch thick can easily be broken between the fingers. These properties, however, at once change upon heating the iron; it then becomes very much softer, and as malleable as it was before brittle, and can be cut with the scissors with the greatest ease, as well as bent to and fro numerous times without breaking. Iron so deposited was supposed to be pure iron, but the researches of the late Professor Graham on the occlusion of gases in metals caused Professor Jacobi to examine it more carefully, when he found that it in reality contained a considerable amount of hydrogen gas. Still more recently this iron has been investigated by R. Lenz, who finds that all such electro-deposited iron contains very much hydrogen, with more or less carbonic acid, carbonic oxide, nitrogen, and water, and that it may have occluded in its substance as much even as 185 times its own bulk of these gases, principally hydrogen, which are evolved again on the application of heat. When heated out of contact with the air or oxidizing matters, this iron changes colour, and becomes of a colour exactly resembling platinum; and if now placed in water, a portion of the iron is oxidized at the expense of the oxygen in the water, whilst the hydrogen set free is at once absorbed, or again occluded by the rest of the iron.

Ores.—*Native Iron.*—Iron occurs in a native state; but the quantity found is so small as to be of no practical use. Native iron is also found in meteoric stones, which consist chiefly of iron and nickel; but these substances are of no interest to us. Iron combined with oxygen, carbon, carbonic acid, and some other substances, is the form which arrests our attention.

So great is the affinity of iron for other substances, that its ores seldom occur in a pure condition; and as the foreign matters form the quality of the metal smelted from the ores, it is evident that each peculiarity of the ore is imparted to the iron manufactured from it. Those minerals which contain at least 20 per cent. of metal are considered ores; if they contain less, they are denominated fluxes. The richest and purest ores are found in the primitive rocks. But as some ores, of more recent origin, form a metal peculiarly qualified for certain purposes, they are not less valuable than the former. Those minerals which constitute useful iron ores, we shall here proceed to notice.

Magnetic Iron Ore; Loadstone, or Magnetic Ore.—Protosesquioxide of iron. This occurs crystallized, and also granular, earthy, and compact. Its sp. gr. is 5·09. It is of a black colour, metallic lustre, opaque, hard, brittle, and forms always a black powder, when rubbed or pulverized. It is attracted by the magnet, and is fusible in a very strong heat. When pure, it contains from 69 to 72 per cent. of metal. Some of these ores are hydrates, and contain 7 per cent. of water; and in this case, the metallic contents are diminished in ratio. It occurs in the west of England and in Yorkshire. Very extensive beds and veins of it are found in the counties of Warren, Essex, and Clinton, in the State of New York, also at Belmont, Canada, in Norway, and in Lapland. Imbedded in granite, syenite, and syenitic rocks, it occurs in Orange, Putnam, Saratoga, Herkimer, and other

counties in New York; in New Jersey, Pennsylvania, Virginia, Vermont, New Hampshire, Connecticut, Arkansas, Missouri, and we may add, in most States of the Union. No kind of ore is more generally diffused in the United States, either in larger quantities or better quality. The Swedish iron, so justly celebrated for its good qualities, is chiefly manufactured from magnetic ore.

The purest kinds of this ore furnish, by good management of the furnace, about 70 per cent. of crude iron; on an average we may calculate on 50 to 55 per cent. of metal. A specimen of this ore from Lake Champlain, furnished by analysis,

Protoxide of iron	17·9
Peroxide „	81·8
Alumina and silica	0·3

and a specimen from South Carolina 69·5 protoxide and peroxide, 1·5 alumina, 20·0 silica. The first variety may be considered a very pure, and the latter an impure, ore of it.

To this class of iron ores we may also range those magnetic ores which contain titanic acid. This substance is frequently found in the magnetic ores of New York, amounting from 1 to 10 per cent. of them, and in single specimens even more. A specimen of ore from Lake Champlain furnished in 100 parts,

Peroxide of iron..	70·00
Protoxide „	12·31
Phosphoric and titanic acids	6·19
Silica	·36
Manganese	·33

This ore is also found to contain, frequently, iron pyrites, galena, blende, arseniuret, copper pyrites, heavy spar, and other more or less injurious substances.

Red Oxide of Iron; Peroxide of Iron; Specular Ore; Red Hematite; Micaceous Ore.—This iron ore occurs in nearly all geological formations, and the crystallized variety chiefly in primitive and metamorphic rock. The red hematites of Lancashire and Cumberland are perhaps the richest iron ores in England; the deposits of Furness alone were estimated in Feb. 1872 as producing annually 800,000 tons of ore, the richest deposits having generally been discovered at or near the junction of the mountain limestone and the slate (silurian) rocks. About three-fifths of the entire quantity raised in these counties is of a hard rocky nature, containing about 60 per cent. of metallic iron, of nearly a uniform quality, except that in some of the mines on the eastern side of the northern series it is slightly mixed with quartz, and rather more silicious in character. In the north Lancashire district is a hard, red, fine ore, containing about 55 per cent. of metallic iron, occasionally mixed with considerable quantities of manganese. Red hematite has been discovered to exist in great abundance in the United States; it is also found massive, and as red ochre, combined with clay, shells, and other substances. Reddle is an impure kind of it. It is easily distinguished from other ores, by affording a red powder when rubbed upon a white substance; but as some of the varieties are very hard, and others feel unctuous, like graphite, a hard substance —white porcelain—is required to bring out the colour. The crystallized varieties are generally pure and very hard, and may furnish 70 per cent. of metal; its sp. gr. is 4·5 to 5·3; the compact ore is 4·2. The crystals are of great lustre, brown, often black; the massive varieties are some-

Specimens of Lancashire and Cumberland Ores analysed by J. T. Smith, contained;—

	1.	2.	3.	4.	5.
Sesquioxide of iron	85·93	91·87	79·14	92·45	83·05
Protoxide of manganese	0·32	0·30	0·66	0·04	0·08
Silica (in solution)	0·11	0·10	0·16	0·09	0·07
Alumina „	0·14	0·30	0·06	0·05	0·45
Lime „	0·29	0·28	0·22	0·32	3·54
Magnesia „	trace	trace	trace	trace	0·72
Carbonic acid	..	..	..	..	2·41
Phosphoric „	0·02	..	trace	trace	trace
Sulphuric „	..	..	..	..	0·04
Water	1·02	0·65	2·31	0·46	3·50
Ignited insoluble residue	12·53	6·34	17·06	6·87	6·70
	100·36	99·84	99·61	100·28	100·56
Ignited insoluble residue;—					
Silica	11·63	5·80	15·78	6·77	5·87
Alumina	0·44	0·36	1·03	traco	0·62
Sesquioxide of iron	..	..	..	..	..
Lime	0·04	trace	0·14	trace	0·04
Magnesia	trace	trace	trace	trace	trace
	12·11	6·16	16·95	6·77	6·53
Iron, total amount	60·15	64·31	55·40	64·71	58·13

times earthy and red, or brown-red. In thin laminæ the ore is translucent, and of a bright red colour. Some kinds of it are attracted by the magnet, which may be caused by particles of magnetic ore. With this kind of ore are also classed the different argillaceous ores, which frequently are so poor in metal as to contain only 5 or 10 per cent., but are nevertheless of a perfectly red, often brown-red colour.

All this kind of ore furnishes a superior quality of iron, which is distinguished for tenacity and softness.

A specimen of brown, or red-brown, fossiliferous iron ore, which is smelted in Pennsylvania, and Wayne county, New York, contained,

Peroxide of iron	51·50	Silica	6·00
Carb. of lime (shells)	24·50	Alumina	7·50
Carb. of magnesia	7·75	Moisture	2·75

On an average, these ores furnish from 36 to 50 per cent. of iron. Those which furnish less than 30 per cent. of metal are generally not smelted. Some of them, particularly those in the Southern States of America, are the result of the decomposition of pyrites, and the ore-beds show iron pyrites below the water levels. These ores also contain titanic acid, as is seen in some of the Pennsylvania ores; they are then very refractory. Alumina is the most general companion of these ores, and may be considered one of the causes of the good quality of the iron which they furnish.

Brown Hematite; hydrated sesquioxide of iron; brown and yellow ore; bog ore; pipe ore; prismatic ore. This is a very abundant iron ore, and a source of cheap metal; it is mined extensively at the Forest of Dean, Gloucestershire, in Cornwall, Devonshire, France, and Belgium; it is also mined in Wales, Wiltshire, Oxfordshire, and forms the bulk of ore in the United States. Hematite is essentially a hydrated peroxide, with definite quantities of water, which vary from 9 to 13 per cent. In its purest form it contains from 50 to 62 per cent. of metal. The varieties of this ore are very numerous; it occurs in all shades of colour, from black to a faint yellow. The brown or black fibrous ore is of the best quality, but the compact kinds are more or less adulterated with silica and alumina, generally with the first. Bog ore often contains from ½ to ¾ per cent. of phosphorus. Yellow ores are mingled with clay, lime, magnesia, and other substances; the brown ore often contains large quantities of manganese, from which no ore of this kind is entirely free. The powder of all the varieties of this ore is yellow.

All these ores are of recent origin. They are the result of the decomposition of pyrites, carbonates, arseniurets, and other compounds of iron, and often assume the forms of vegetable or animal remains.

The best kinds of this ore from the coal formations, which are generally the result of the decomposition of the argillaceous carbonates, contain on an average not more than 30 per cent. of metal. They generally are mixed with a variety of foreign substances, as the following specimen from Westmoreland county, Pennsylvania, shows;—

Peroxide of iron	77·00	Organic matter	1·22
Oxide of manganese	4·50	Water	12·00
Alumina	·50	Silica	4·00

In the Forest of Dean large quantities of brown hematites have been mined and smelted in the local works: the iron is of a red-short nature, but especially celebrated for the manufacture of tin plates. These ores are wrought from deposits in Lancashire and Cumberland, Northumberland, and Durham; the carboniferous limestones of Derbyshire, Somersetshire, and South Wales contain deposits which are also wrought; but it is from the Dean Forest, Lancashire, and Cumberland mines that the chief supply is at present obtained.

By analysis it has been found that the average composition of the calcareous ores of Dean Forest is nearly as follows;—

		2.
Peroxide of iron	54	67·0
Carbonate of lime	35	24·3
Clay	7	6·5
Moisture	4	2·2
	100	100
Metallic iron	37·5 per cent.	46·5 per cent.

The first result will probably seem a low yield to persons who use calcareous ores in mixture with others, but from numerous assays, as well as experimental trials in the blast furnace, it fairly represents the produce of the mass of these ores. When the specimens have been carefully selected the produce is higher, as in the second example from the same locality.

Spathic or Sparry Ore, crystallized carbonate of iron. This is protoxide of iron in combination with carbonic acid. This ore most frequently contains also carbonate of manganese, and carbonate of magnesia. When perfectly pure, it ought to consist of 62·1 protoxide of iron, and 37·9 carbonic acid, which is equal to 48·3 parts of metal. The colour of this ore is white, yellowish, and often of a reddish hue, or flesh-coloured. There are also fine brown varieties, which may be considered partly oxides; and often the whole mass is thoroughly oxidized, and still retains its lustre and form of crystals. Its sp. gr. is 3·7 to 3·8; its lustre vitreous, and the streak or powder white. This ore is in some specimens translucent, particularly in thin scales. It is hard and brittle.

It is a very interesting species of iron ore; when pure it forms good steel with the greatest facility; in fact, it is converted into steel with less labour than into fibrous iron. German steel is exclusively manufactured of this ore, from the pure varieties of Styria and western Germany; for

these reasons it is called steel ore. Notwithstanding this ore bears a high reputation as an element for the manufacture of steel, yet cheap steel can never be made from it, nor good steel, unless it is treated with particular care. But it is adapted to produce the strongest and most fibrous kinds of wrought iron.

It is very abundant in Europe, but not in the United States. Sparry ore is found in Vermont; and that from Plymouth, U.S., furnished by analysis—carb. of iron 74·28, carb. of magnesia 16·40, carb. of manganese 6·56 and oxide of iron ·3. It also occurs to some extent at Roxbury. This ore is most generally impure; it is usually mingled with pyrites and sulphurets of various descriptions, which of course render the iron manufactured of it of less value than other and purer kinds of iron.

Argillaceous Ore, compact carbonate of iron, occurs chiefly in the coal formations, but its presence is not confined to these localities. When oxidized, it forms hydrated oxides, brown or yellow hematites; it is from these that the iron of Pennsylvania is chiefly manufactured. In its original form it is found in round or flattened lumps, spheroids, imbedded in clay, clay-slate, sandstone, shale, or limestone, and arranged in regular veins. These balls range from globules of the size of peas to masses of two and more tons in weight; but as there are often large quantities of dead slate between the balls, the ore is expensive, however soft the shale may be. When the spheroids oxidize, the oxide assumes the form of shells ranged in circular layers, like an onion. It appears that the oxidation progresses either by periods, or, that at one time of the process more of the impurities are removed than at others, which causes a different density in the hydrated oxide, and a consequent formation of strata. This ore does not often contain more than 33 per cent. of metal. Its composition is that of the sparry ore, but it contains always some alumina, and some silica, and lime. The ore, when dried or roasted, emits the peculiar argillaceous odour incident to clay and clay ores. Its fracture is always close-grained. Sp. gr. 3· to 3·5.

All the great coal formations hitherto discovered contain argillaceous and carbonaceous iron ores in greater or less abundance. The Staffordshire, South Wales, North Wales, Derbyshire, Shropshire, and Scotch coal-fields, contain valuable seams of argillaceous iron ore. In the Durham, Lancashire, Somersetshire, and other minor coal-fields, the argillaceous ores exist in smaller quantities, and produce when smelted crude iron of an inferior quality.

The South Wales coal-field stands pre-eminent for the number and richness of its seams of argillaceous iron ores. The aggregate thickness of the seams measures 21 ft. The average percentage of metal in the ores exceeds 32 per cent. We subjoin the analyses of the ores from a number of seams wrought by the Dowlais Iron Company, from which their blast furnaces at Dowlais are chiefly supplied.

ANALYSES OF THE PRINCIPAL SEAMS OF ARGILLACEOUS IRON ORE IN THE SOUTH WALES COAL-FIELD.

	1.	2.	3.	4.	5.	6.	7.
Carbonate of iron	74·5	86·	77·1	62·	42·7	59·5	68·2
Silica..	14·5	8·3	15·9	27·5	42·7	36·9	21·6
Alumina	8·3	·2	3·8	7·8	7·5	1·9	5·4
Carbonaceous matter	..	4·2	1·8	2·1	2·8	..	3·8
Lime	·8	..	·4	..	·1	..	..
Moisture and loss	·6	1·3	1·	·6	1·4	1·7	1·
Phosphoric acid	trace	..	..	..	2·8	..	..
Manganese	1·3	..	..	..	..	..	..
	100·	100·	100·	100·	100·	100·	100·
Percentage of metallic iron ..	35·9	41·46	37·2	29·5	20·6	28·7	32·9

These analyses, taken from the centre of the iron manufacture in this district, may be considered as fairly representing the mean composition of the Welsh argillaceous ores, since the variation at other workings, eastward and westward, is inconsiderable.

The richness of the respective seams in this basin is influenced by the distance between them. Thus, where two or more seams of iron ore exist with only a thin parting, their mean percentage will be found higher than that of seams having a greater thickness of ground interposed. The general character of the associated earths is influenced by the composition of the matrix, and also, but to a minor degree, by the adjacent seams of rock, shale, or clod. Seams of argillaceous ore, having either a roof or bedding of silicious rock, invariably contain a large percentage of silica. The lowest seams of ore, as they approach the mountain limestone, are found to contain a notable percentage of lime, a substance almost entirely wanting in the richer seams of the upper series.

On analysing specimens from 68 seams, the produce of which was used in the Dowlais furnaces, including the whole of the argillaceous ores of the north outcrop, it was found that 47, or more than two-thirds of the number, yielded 30 per cent. and upwards.

The Staffordshire coal-field contains numerous seams of argillaceous iron ores, from which the blast furnaces of the district derive their principal supply. In richness they are slightly inferior to the average of the Welsh ores, but they are equal to them in the quality of the resulting iron.

The analysis of a very rich specimen from this field, obtained near Dudley, gave;—

Carbonate of iron	78·3
" lime	5·2
" magnesia	4·7
" manganese	1·7
Alumina	1·8
Silica	5·6
Phosphoric acid	·2
Carbonaceous matter and loss	2·5
	100·

Metallic iron 37·7 per cent.

The North Wales coal-field contains seams of argillaceous ore, but the average yield of metallic iron does not on the raw ore exceed 25 per cent.

The Derbyshire coal-field supplies a considerable quantity of these ores, but the product is generally inferior to that of the Welsh ores. According to M. Bunsen, the composition after calcination of those smelted in the Alfreton furnaces was as follows;—

Peroxide of iron	60·242
Silica	25·775
Alumina	6·583
Lime	3·510
Magnesia	3·188
Potash	·743
Manganese	traces
	100·

Metallic iron 41·7 per cent.

The Yorkshire coal-field contains numerous valuable seams of argillaceous iron ores. We annex the composition of five of the seams under the manor of Healaugh Swaledale, according to analyses made by Dr. Odling.

COMPOSITION OF YORKSHIRE ARGILLACEOUS IRON ORES.

	1.	2.	3.	4.	5.	Mean.
Carbonate of iron	80·50	70·80	75·80	79·00	65·59	74·3
" lime	3·48	11·72	4·72	8·36	21·28	9·9
Silica and clay	8·72	10·72	10·60	10·30	6·16	9·3
Carbonate of magnesia	·25	·63	..	..	1·23	·43
" manganese	traces	traces	traces	..	..	..
Sulphur	..	..	..	..	..	·63
Carbonaceous matter	7·05	6·13	8·88	2·33	5·74	5·44
Moisture and loss	..	..	..	..	..	..
	100·	100·	100·	100·	100·	100·
Yield of metallic iron	38·8	34·17	36·6	38·1	31·6	35·8

The Scotch mineral field contains large quantities of argillaceous iron ore. Before the discovery of the more fusible carbonaceous variety these ores formed the chief supply of the blast furnaces in this district.

COMPOSITION OF SCOTCH ARGILLACEOUS IRON ORES ANALYSED BY DR. COLQUHOUN.

	1.	2.	3.	4.	5.	6.	7.	8.
Protoxide of iron	35·22	45·84	42·15	38·80	36·47	47·33	43·73	53·03
Peroxide of iron	1·16	..	·80	·33	·40	·33	·47	·23
Carbonic acid	32·53	33·63	31·86	30·76	26·35	33·10	32·24	35·17
Protoxide of manganese	..	·20	..	·07	·17	·13	..	..
Lime	8·62	1·90	4·93	5·30	1·97	2·00	2·10	3·33
Magnesia	5·19	5·90	4·80	6·70	2·70	2·20	2·77	1·77
Silica	9·56	7·83	9·73	10·87	19·20	6·63	9·70	1·40
Alumina	5·34	2·53	3·77	6·20	8·03	4·30	5·13	·63
Carbonaceous matter	2·13	1·86	2·33	1·87	2·10	1·70	1·50	3·03
Sulphur	·62	..	..	·16	..	·22	·02	..
Moisture	..	·99	..	..	..	..	..	..
	100·37	100·68	100·37	101·	98·09	97·94	97·66	98·59
Yield of metallic iron	28·4	35·3	33·	30·	28·4	36·7	34·	40·9

A fine quality of argillaceous ore is extensively smelted in Maryland; it is found in the tertiary deposits near Baltimore, imbedded in a tough clay, in horizontal layers near the surface of the ground, and seldom extending to the depth of 30 ft. The ore, evidently carried by floods from the coal region, is found associated with well-preserved trunks of trees and other vegetable matter. It is very pure, close and compact, and furnishes a superior iron for the forge.

Blackband or *Carbonaceous Iron Ore*.—Most valuable seams of carbonaceous iron ores belong to the Scotch and North Staffordshire coal-fields. The thickness of the seams in these fields varies from a few inches to several feet. It is observed, however, that the thickest seams are not so rich in metal as the thinner, and as a rule the quality is also inferior. The general composition of the richest of the Scotch carbonaceous iron ores will be seen from the following analyses, principally by Dr. Colquhoun:—

	1.	2.	3.
Protoxide of iron	[illegible]	[illegible]	[illegible]
Peroxide of iron	[illegible]	[illegible]	[illegible]
Carbonic acid	[illegible]	[illegible]	[illegible]
Lime	[illegible]	[illegible]	[illegible]
Magnesia	[illegible]	[illegible]	[illegible]
Silica	[illegible]	[illegible]	[illegible]
Alumina	[illegible]	[illegible]	[illegible]
Carbonaceous matter	[illegible]	[illegible]	[illegible]
Moisture	[illegible]	[illegible]	[illegible]
	100·	100	100·
Yield of metallic iron	[illegible]	[illegible]	[illegible]

[illegible]

ANALYSES.

	1.	2.	3.
[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

fluid; and the labour of transforming crude iron into wrought iron is least when the impurities can be removed in the shortest time and with the least labour.

Iron and oxygen are not fusible at all; they do not assume a metallic form until they become a salt—such as magnetic oxide. Iron may combine with a little chlorine, which causes it to be fluid; but this renders it extremely brittle when cold. We have no other evidence of the combination of iron and chlorine, than that iron melted under a cover of chlorides is very pure, fluid, and brittle, of a bright silvery colour and lustre. When this very fusible metal is gently heated, it is converted into very refractory iron—becoming fibrous and extremely tenacious. The melting of iron under a cover of chlorides is not so easily performed; it succeeds best when turnings of good grey cast iron are melted by applying a very gentle heat, with a flux composed of common salt, lime, and alumina.

The affinity of iron for sulphur is very great; it is tedious to remove all the sulphur from it when once combined. Iron absorbs sulphur from all other metals, from fluxes, and from carbon. Oxygen or chlorine are the only substances which will remove sulphur, and before they enter into combination with iron all of it must be removed. The various forms of the legitimate compounds of iron and sulphur are of no interest to us. Small quantities of sulphur, quarter of 1 per cent. in the metal, not only are injurious to iron, but cause expense and vexation in refining. Much sulphur in iron causes it to be cold-short, brittle, and hard when cold; a little produces hot-short and brittleness when the iron is hot. Sulphur has a remarkable influence on iron; it is similar to that of cadmium. At low heats it does not cause fluidity; the iron assumes a mushy appearance, but is not fluid. When the same iron is heated to a higher degree it becomes perfectly fluid, white, and compact. Similar phenomena occur with carburets of iron; and we are inclined to conclude by analogy, that such is the case with all alloys, particularly when one substance is far more volatile than the other. When iron is combined with sulphur to such an extent as in pyrites, it is extremely hard; oxygen does not attack it, and strong acids do not affect it. When it contains only a trace of sulphur, it is far more liable to corrosion than pure or alloyed iron. Sulphur is not attacked by oxygen, whereas iron is, and it requires the close cover of sulphur to protect it. When metals which have no particular affinity for sulphur, such as gold, are mixed with the sulphuret of iron—the decomposition of the sulphuret advances more rapidly. It appears that in this case moisture finds access into the pores of the metal, which accelerates the oxidation. This electrical action, which is frequently observed in metallic alloys, arises in consequence of imperfect union; it is by no means a universal case. Iron appears to melt with sulphur in all proportions; but it either requires a certain amount to form a chemical union of perfect fluidity, or so high a degree of heat that a proper arrangement among the particles becomes possible. In the latter case, a union is formed which is not easily destroyed. When iron containing sulphur is heated red hot, and suddenly cooled in water which is a little warm, a smell of sulphuretted hydrogen is perceptible, even when only a trace of sulphur is present. A quantity of sulphur in ore, coal, or flux, which is so small as to escape the most skilful assayer, is sufficient to cause iron to be red-short.

Phosphorus and Iron.—Phosphoric acid is frequently found in iron ores; quite as well in those which are primitive as in those of the coal formations and younger ores. Phosphoric acid in contact with coal is converted into phosphorus; and as iron has strong affinities for phosphorus, we always find it in the metal if it has been in the ore or the fuel—particularly in grey metal. When white metal is smelted, a large quantity of phosphorus is absorbed by the slag as phosphoric acid. Phosphorus, unlike sulphur, causes iron to be very fluid, even in small quantities and at low heats. Owing to this property, phosphorus is less vexatious when present in iron than sulphur. Iron with phosphorus is white, close, and compact; assumes a high polish, and is less attacked by oxygen than other alloys. It is extremely brittle, so that the least force will break it when cooled below 32°. Phosphorus will drive sulphur from iron when the latter is present; still they may be both in crude iron at the same time. Sulphur is removed before phosphorus can be evaporated. Iron which contains phosphorus melts easily, works well in refining, is easily welded, and is in fact very manageable.

Carburet of Iron.—We do not know if a carburet of definite proportions is in existence; grey cast iron is a mere mechanical mixture, and so is steel. We are not acquainted with any carburet. It appears that the refractory character of carbon does not admit of an intimate union but under forced conditions. Carbon will liberate itself in spite of the affinity existing between it and the metal. Carbon unites with iron very readily in all proportions, from a small per cent. of iron in graphite, to a quarter of 1 per cent. of carbon in steel. The compounds containing much carbon are not fusible; they are mere black powders. It appears that iron cannot absorb more than 6 per cent. of carbon—grey or white crude iron—without losing cohesion. Iron with carbon may be soft when grey, but is hard when white. Grey iron is imperfectly fluid—limpid—at all times; white iron is mushy, like a sulphuret, but assumes a perfect fluidity when heated to a high degree. There is a striking similarity between the combinations of sulphur and iron, and those of carbon and iron, which extends even farther than mere fluidity. White iron has all the qualities of a perfect alloy; grey iron that of a mechanical mixture. We will endeavour to show the nature of this difference. White iron, that is a perfect alloy, we do not observe but in crude iron which has been smelted from sparry ore, and in hardened steel. The intimate union of carbon and iron which is requisite to form an alloy is not in existence in grey iron, and in steel only when hardened. In white crude iron, sufficient carbon remains in union with the metal to cause its fluidity; this, for want of other matter, is chiefly effected by carbon. When more carbon than about 6 per cent. is removed from this iron, it ceases to be fusible in the furnaces. The carbon is naturally in very intimate connection in the specular ore, and the heat in smelting removes merely a part of it, and chiefly oxygen. A definite arrangement of the atoms of carbon and iron exists already in the ore, which is in a great measure destroyed; a certain portion of the ore, however, retains its original constitution, which with the difference of oxygen or these particles of carburet, are surrounded by a certain number of particles of pure iron which prevent their decomposition. Thus it is that the

carbon in this iron resists the effects of oxygen for a longer time than that in other kinds of iron, and also in steel: and to this extent we may call this iron a true alloy. It is the intimate contact of a few atoms of carbon which imparts character to a large mass of iron. In grey iron, or tempered steel, the atoms of carbon fill merely the pores; and if we assume that carbon is dissolved in hot iron—which we are permitted to do because similar cases happen with other substances—we at once discover the cause of hardening. It is the sudden contraction of the metal, and its strong cohesion, which condenses the carbon between its particles, and forces it to remain in chemical union. The strong cohesion in the atoms of carbon is the cause of grey iron; and the want of cohesion between the atoms of the latter, or want of fusibility, is the cause of the hardening of this metal by sudden cooling. We see here at once the philosophy of hardening and tempering, and that an alloy of arsenic or phosphorus cannot be tempered or hardened, because that essential condition, the separation of the particles, is wanting. Carbon crystallizes at a much higher heat than iron, and is solid; it also separates before iron which is slowly cooling has sufficient cohesion to prevent its crystallization. Carbon thus causes hardness in the same manner as other substances; and if we disregard tempering, or annealing, there are substances which impart a higher degree of hardness to iron than carbon. It appears that manganese induces the solution of carbon in iron more than other substances; still, there are some other metals which produce the same effect. Iron exerts a powerful influence on carbon at low heats and in the presence of other matter. It absorbs it and retains it as a black powder. This is the case in grey iron, and blistered and annealed steel. In strong iron, and grey iron of great cohesion, carbon is condensed into graphite and crystallized. We infer from these and other facts, that carbon exists in white steel, white iron, and in hardened steel, in the form in which we find it in the diamond.

Silicon.—This substance appears to have as much affinity for iron as carbon; and if not found in such large quantities, it is nevertheless present in all commercial iron and in the best steel. The general diffusion of silicon—or silex, silica—its presence in all iron ores, together with its strong affinity for iron, indicates as certain its presence in iron. Silicon, alloyed with iron, causes the metal to be very hard and brittle. All the iron smelted from silicates, in which the oxides of iron are united by fusion to silex, is extremely hard and brittle; more so even than phosphorus would make it. When crude iron is largely alloyed with silicon, it causes the wrought iron made of it to be brittle and soft; it forms therefore the poorest kind of bar iron. Half of 1 per cent. of silicon causes crude iron to be brittle; but iron may contain 10 per cent., and more, of silex, and be perfectly malleable. The first is an alloy, the second a mechanical mixture. When silicious iron is exposed to a gentle heat, tempered in sand or iron ore, the silicon oxidizes and separates from the particles of iron and forms particles of silex, which do not combine chemically with iron. Here silex is in the same form as carbon in annealed iron. Berzelius relates that he assayed a specimen of perfectly malleable iron, which furnished 19 per cent. of silex. Fibrous wrought iron may contain large quantities of silex, and be perfectly malleable and ductile, but when the iron contains in the meantime carbon, an exposure to a high red heat will convert the silex into silicon, and cause the iron to become short and brittle.

Aluminum.—We shall not allude to the alloys of boron, selenium, tellurium, and some other substances, because these are of no practical value. Aluminum appears to have a beneficial, toughening influence on iron, and it is asserted that wootz—East Indian steel—contains this metal as alloy. It is certain that all iron smelted from clay ores is stronger than that smelted from any other kind of ore, particularly in the form of wrought iron. Pure alumina combines readily with iron when borings of grey cast iron are smelted with it. Such cast iron contains, however, silicon and other substances, which interfere with the true character of the alloy. It may be difficult to form a pure alloy of iron and alumina, because a high heat is required, at which other substances whose presence cannot be avoided enter into combination. In fluxing iron and aluminum by a substance which has a strong affinity for both, so as to reduce the point of melting, pure alloy may be formed, provided the flux is volatile and may be driven off. Pure carbon or arsenic may form such a flux. It is stated that iron alloyed with alumina is very hard and tough, and exhibits the nature of Damascus steel. This is a strong indication of the refractory nature of the alloy; it does not combine uniformly with the mass of the metal.

Arsenic.—This substance causes iron to be very fluid, hard, and brittle. One part of iron borings melted together with two parts of arsenious acid form an arseniuret of iron, of definite constitution. The best manner to alloy iron with arsenic is by cementation. Arsenic combines very intimately with iron; its alloy cannot be hardened like steel, nor can it be annealed. When the heat in melting this alloy is too strong, the arsenic evaporates rapidly, throwing out iron which burns with greater brilliancy than any other compound of iron. It burns in similar manner to a very hot zinc alloy, but with more vigour. Notwithstanding the great affinity between iron and arsenic, in cooling or crystallizing both separate to a certain extent, but in a different manner than iron and carbon. When an arsenical alloy is cooled and polished, it shows on examination with a microscope a mass of dark crystals imbedded in a bright white metal, which forms a regular network, filling the spaces between the crystals. We suppose the crystals may be iron and a little arsenic, and the cementing metal chiefly arsenic with a little iron, these are conditions which exist in other alloys. If this alloy is tempered at a red heat, the arsenic evaporates, and causes the remaining metal to be extremely brittle. The same cause is active in hardening this substance. If the metal thus weakened by tempering or hardening is melted again, it forms a coherent, hard, compact iron, but with less arsenic. This alloy, so long as any arsenic is perceptible, cannot be forged or welded; it is hot-short and cold-short.

Arsenic exerts a peculiar influence on iron; it causes cast iron to be extremely brittle, but when removed from it by refining, and converting it into bar iron, it is found to be exceedingly soft and pure. Most of that iron which furnishes the best cast steel is manufactured from ores which contain arsenic.

Chromium.—Iron combines with chromium quite easily, and forms an exceedingly hard alloy,

which is brittle. It is, however, an excellent preservative of iron from rust. By converting crude iron into bar iron, all the chromium contained in it is easily removed. Chromium is very refractory, and consequently we entertain serious doubts of the brittleness of the alloy of this metal and iron. Sixty parts of iron alloyed to forty of chromium is stated to be very hard and tenacious, cutting glass equal to a diamond. Chromium, as well as iron, are both refractory, and, as the heat required to melt either is high, it is difficult to obtain the alloy without an admixture of other matter; to the latter must be assigned the brittleness which is asserted to belong to it. In smelting these metals, either from their ores together, or omitting them directly, in all instances their purity must be doubted. The only manner in which a considerably pure alloy is obtained is, by smelting filings of pure wrought iron in a clay crucible lined with the pure oxide of chromium and carbon; the first forms a second lining in the latter. The alloy thus obtained is, according to our own experience, very hard, uniform, and tenacious, and shows no signs of crystallization when polished.

Titanium.—This metal appears to be so refractory, and has so little affinity for iron, that it will not admit of a union. A union is, however, effected in the same manner as between lead and iron, that is, by employing a substance which has affinity for both. We have no experience in forming this alloy, and the scarcity of the metal hardly admits of its practical use.

Zinc.—As cast metal, the alloy is worthless; it never will obtain strength. In refining crude iron which contains zinc, the latter evaporates; and by perseverance a fine rough iron may be obtained. In this respect arsenic is superior to zinc; it works with more facility.

Manganese.—The similarity of this metal with iron subjects it to the same laws. It forms similar compounds. In combining with iron it causes it to be more fluid, and consequently harder than it is naturally. This metal is one of the best alloys in combination with iron which is to be converted into wrought iron. It causes cast iron to be hard and brittle; but this assertion must be taken with due allowance for the influence of other matter. The protoxide of manganese is a strong alkali, and forms a very fusible fluid slag with silex. In refining iron which contains manganese, the latter is oxidized before any iron is attacked by oxygen; and its strong affinity for silex removes the latter from the iron. No manganese is ever detected in wrought iron. Crude iron contains it when smelted from ores in which it exists. In manufacturing wrought iron, this substance is, on account of its alkaline and refractory nature, the most useful auxiliary.

Nickel and Cobalt.—These metals, alloyed with iron, appear to exert a similar influence upon it. Nickel is found native and alloyed, in meteoric iron. This alloy has been little examined, and is, to all appearance, of slight practical use.

Antimony.—This combines readily with iron; the alloy is very hard and very brittle. It is useless. The oxides of the metals mixed, and melted with carbon in a crucible, form an alloy at a low heat.

Lead.—This substance does not combine very readily with iron, particularly when the latter is in combination with carbon. When contained in the ores of iron, it separates in the blast furnace from the iron and forms a stratum at the bottom of the hearth. The crude iron thus smelted is extremely hard, becomes very fluid in melting, and works admirably well in the forge fire and puddling furnace, and makes a very tenacious, fine, bright, fibrous iron, of first-rate quality. The fluid alloy of lead and iron is of no practical use; when cast it is brittle.

Tin combines readily with iron, and both mix in various proportions, and form definite compounds. The alloy is always hard, and this hardness increases in proportion to the quantity of tin, until the latter is more than an equal part. This alloy is heavier than iron itself—of greater hardness and lustre, 57·9 of iron and 42·1 of tin is said to be an alloy particularly distinguished. Iron thinly coated with tin forms tin plate. For this purpose a very pure tin is required, or at least a metal free from easily oxidized substances.

Tin added to iron in the puddling furnace, to the amount of $\frac{1}{2}$ or 1 per cent., causes a bright metal, which works remarkably well in squeezing and hammering. It forms a strong iron, malleable, neither red-short nor cold-short. The application of tin for this purpose is rather expensive; we may obtain the same, or similar results, by other means less costly.

Copper.—Copper has no marked affinity for iron, and combines with it only in small quantities. Still, $\frac{1}{10}$ of 1 per cent. causes iron to be red-short. Mixed to cast-iron, it causes cold-short. Wrought iron with copper is stronger, when cold, than pure iron. Its oxides form very refractory silicates, which, together with its permanency under heat, is the cause of its adhering tenaciously to iron. For these reasons it cannot be removed from iron in refining the latter.

Mercury.—Iron does not combine with mercury directly; but when an alloy of iron which contains a metal soluble in quicksilver is brought in contact with it, a combination ensues. Alloys of tin and iron, zinc and iron, silver and iron, may be combined with mercury, and resist the charring heat of wood. It forms a hard, brittle amalgam, similar to that of antimony.

Silver.—Iron melts readily with silver, but the metals separate in cooking, and show the same appearance as arsenic and iron. The alloy is harder and stronger than that of arsenic. This compound oxidizes rapidly. A small quantity of silver, $\frac{1}{2}$ per cent., may be united with iron, and form an intimate union.

Gold.—This metal fuses easily with iron, and fine ornamental works in iron are soldered with it. It is too expensive to form practical alloys with iron. The same may be said of platinum, and the platinum metals. However valuable such alloys may be for scientific purposes, the metallurgist cannot make any use of them.

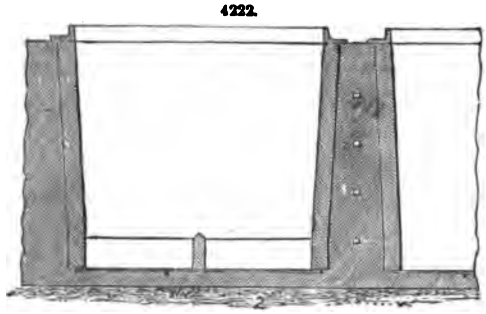
Manufacture of Iron.—The various kinds of iron are procured from the ores we have enumerated; in some cases malleable iron, its purest form, being obtained by merely exposing a certain variety of ore to heat in contact with charcoal fuel, which has the effect of reducing the ore to a metallic condition; but, as a rule, it is far more economical to get it in the first instance in the impure form of cast iron by smelting the ore in a blast furnace; and this is the method most extensively employed.

Cast Iron.—Before the smelting of iron ore is resorted to, it is most generally dressed and

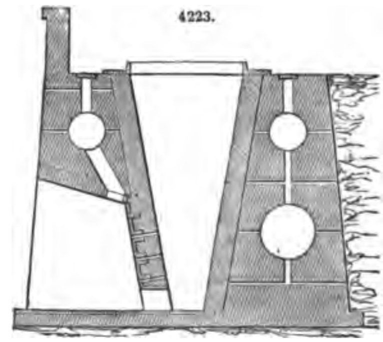
roasted. Few kinds of ore are exempted from this last operation. The yellow hydrates, brown hematites, in fact all the hydrates, need no roasting; the red hematites, clay ores, compact and crystallized oxides, and the specular ore, may be smelted without roasting. Some magnetic oxides, silicates, and carbonates, are also smelted without this introductory operation. All those ores which contain sulphur, arsenic, carbonic acid, carbon, or are not sufficiently oxidized, ought to be roasted.

Roasting.—The operation has been generally described at p. 1598, but we have a few remarks to make here relating particularly to iron; it is performed either in the open air in heaps, or in closed kilns. These kilns vary greatly in their dimensions. The most satisfactory results are obtained with kilns of the description delineated in Figs. 4222 to 4233. The floor of the kiln is formed of

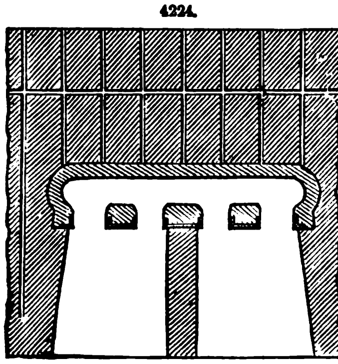
4222.



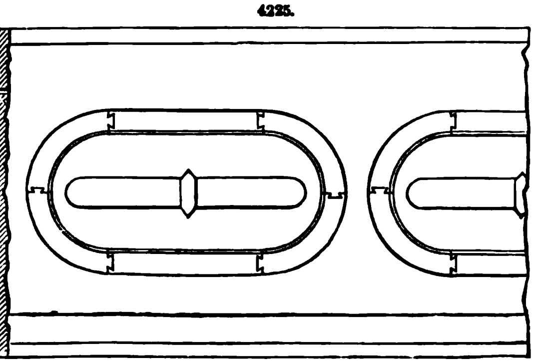
4223.



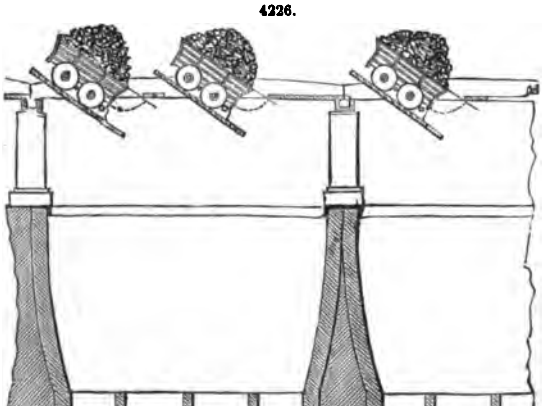
4224.



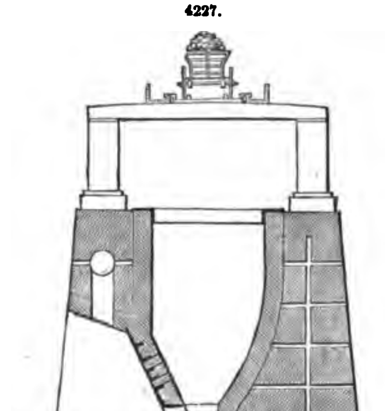
4225.



4226.



4227.

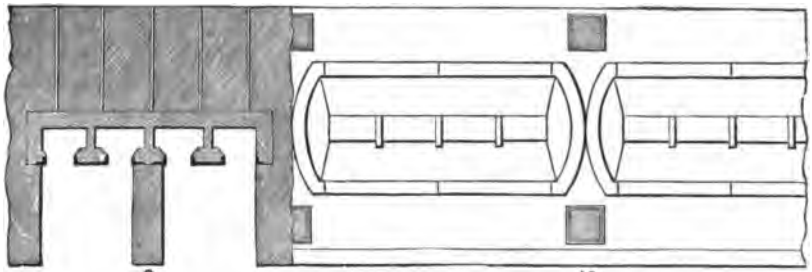


cast-iron plates, about 2 in. thick. The interior measures 20 ft. long, 9 ft. wide at top, and 18 ft. high. It is built of masonry, and lined with fire-bricks 14 in. long. In front are two arches with openings into the inside of the kiln, on a level with the floor, through which the roasted or calcined ore is drawn and filled into barrows or wagons for the furnace. Above these openings, but within the semicircle of the arch, it is usual to leave four or five apertures, 6 or 8 in. square, for regulating the draught. Around the upper edge of the kiln there is placed a cast-iron ring

from 12 to 15 in. wide, with a flange about 6 in. high on the upper side to protect the brickwork from injury during the filling in of the raw ironstone.

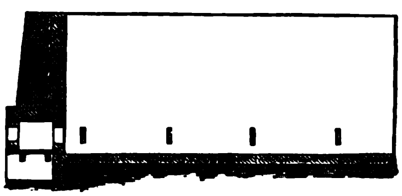
At some works the kilns are of a circular form in the interior; at others they are built square

4228. 4229.

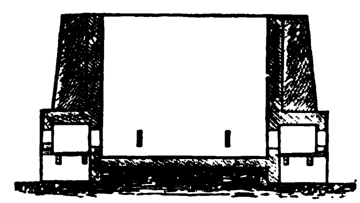


and sharp in the angles, but preference is generally given to the form represented in the figures. Square kilns, or those having sharp angles in their interior, as in Figs. 4230 to 4233, are objection-

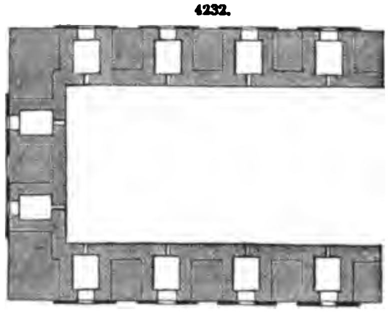
4230.



4231.



4232.



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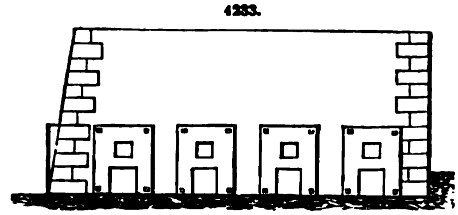


able, on the ground that combustion is slower in the angles than in the centre. If the heat be regulated to properly calcine the centre of the mass, the stone lying in the angles will scarcely have altered from its raw state.

To calcine ores in the kiln two or three small coal fires having been lit on the floor, raw ironstone is placed on top and around them until the whole of the floor is covered with ironstone at a dull red heat. A fresh layer of ironstone, 8 or 9 in. thick, is then added, along with about 5 per cent. by weight of small coal, and, as soon as this layer has reached a red heat, another is added. This addition of fresh layers of raw ironstone and coal is repeated as fast as the previous layers have been heated to the necessary degree.

As a consequence of the small quantity of coal used in the process, by the time that the kiln is filled up with the successive layers of raw ironstone, the lower portions which were first ignited are comparatively cold and fit for drawing.

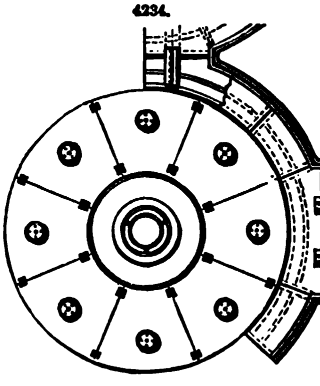
In Scotland and in Staffordshire the calcination of the ironstone is generally effected in the open air. A space is roughly levelled, on which a stratum of coal of a few inches in thickness is laid, upon this a layer of raw ironstone of 10 or 12 in. in thickness is placed, and then a quantity of small coal is thrown over the stone. Additional layers of ironstone and coal are added until the heap reaches to a height of 4 or 5 ft. The bottom stratum of coals is then fired, and in a few hours the whole mass will be ignited. The operation, from the time of firing till the heap has cooled down sufficiently for drawing, will occupy from eight to twelve days, depending on the nature of the stone, quantity and quality of fuel, and size of the heap.

At many works kilns have been erected with a tramroad sufficiently elevated to allow the wagons to discharge directly into the kiln, Figs. 4226 to 4229. This plan is attended with a saving of labour; but with kilns of this shape we do not consider it to be a desirable practice. Each wagon probably holds 2 or 3 tons of ore, which fall in a single heap, measuring perhaps 2 or 3 ft. in height. Over this we will suppose that a quantity of coal is thrown and then left to calcine. If an abundance of coal is used the whole will be properly burnt; but if the quantity of

fuel is proportioned only to the requirements of a well-conducted kiln, the centre of the heap will be more or less imperfectly roasted. From careful observation we are inclined to believe that filling with the shovel is eventually the cheapest plan, and is attended with the most satisfactory results in the blast furnace.

The calcining kilns, Figs. 4234 to 4237, were erected at Middlesborough from the designs of John Gjers. They are of a circular form, and have wrought-iron shells; but, unlike ordinary kilns

4234.



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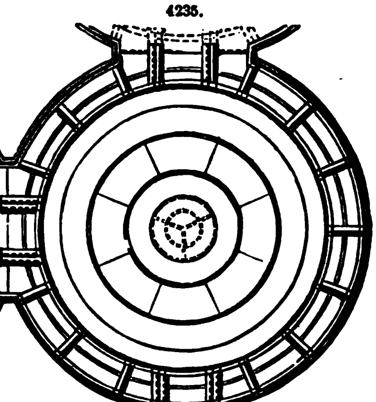
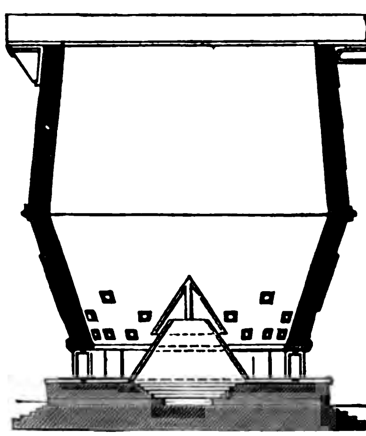
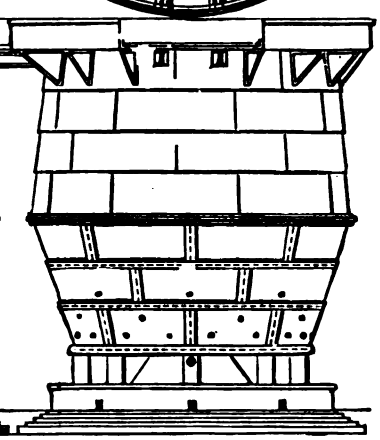




4236.



4237.

of this class, the shells are made of the same shape as the interior of the kilns, so that there is a uniform thickness of 15 in. of fire-brick lining at all parts. The shell and lining of each kiln rest upon an annular cast-iron entablature, which is supported by eight hollow cast-iron pillars cast on the base-plate. By this arrangement a space for drawing the charge is left all round the bottom.

The principal dimensions of each kiln are;—Internal diameter at the bottom, 14 ft.; at the largest part, 20 ft.; and at the top, 18 ft. The height from the base-plate to the top of the columns, 2 ft. 3 in.; thickness of the entablature, 4 in. Height of the shell from the top of the entablature on which it rests to the level of the largest diameter, 9 ft. 2 in., and from that level to the top of the shell, 12 ft. 2 in.; total height of each kiln from the base-plate to the top of the shell, 24 ft. The base-plate is 2½ in. thick, and is 20 ft. in diameter; it is cast in eight pieces, and rests upon brickwork in which the air-passages are formed. The cubic contents of each kiln is 5500 cub. ft.

As will be seen in Fig. 4236, each kiln is provided with a cast-iron central cone, made in two pieces, so arranged that an annular space is left between them. This cone spreads the calcined ore outwards towards the openings through which it can be withdrawn, and it also acts beneficially in assisting to break up any large scars or lumps, partly fused together, which may happen to come down. The central cone might, as far as the mere spreading action is concerned, be made plain and in a single piece; but the form shown in Fig. 4236 has been adopted by Gjers with a view of, in some cases, employing the annular space between the two cones for the admission of waste gas from the furnace. Where the quantity of furnace-gas is not sufficient to be applicable to this purpose, the double cones still furnish the means of giving a good air supply to the kilns.

In the case of the particular kilns we are describing, the central cones are each 8 ft. in diameter at the bottom, and 8 ft. high, and the air is conducted to them through eight channels or flues formed in the brickwork at the base of each kiln. In addition to these passages there are a number of holes, Fig. 4237, for the supply of air, formed in outer shell. The kilns are placed at a distance of 25 ft. apart from centre to centre, and each is surrounded at the top by a gallery formed

of wrought-iron brackets covered with cast-iron plates. The galleries of four kilns are connected with each other at four points, the space between the kilns being bridged over with wrought-iron girders.

Besides the kilns which we have described, there are two others at the same works which have a capacity of 8000 cub. ft. each, and each of these kilns supplies calcined ore to a furnace making from 250 tons to 260 tons of iron weekly. The stone is left in the kilns about two and a half days, and the consumption of small coal and breeze amounts to 1 ton for every 20 tons of stone calcined. In the case of the larger kilns which we have already mentioned, and which are 34 ft. high instead of 24 ft., this consumption has been reduced to 1 ton of fuel for every 25 tons of stone calcined.

Magnetic ore should be roasted, if it is desirable to smelt carburetted iron, for this ore is too compact to admit of the absorption of carbon, and it must be made porous in order to form grey iron. It contains also very frequently iron pyrites, blende, galena, arseniuret, silica, and other substances, which it is necessary to oxidize. When specular iron contains pyrites, which frequently happens, it must be roasted. Sparry ore is to be roasted to remove carbonic acid. If these ores are pure, that is, free from sulphurets, a strong and rapid heat may be made; but when they are impure, a red heat, with a liberal supply of air and moisture, are requisite to succeed well. Impure ore, such as argillaceous ore, clay ore, or hematites, in fact all ores which contain silex, must be roasted gently and slowly at a low heat, and with a long-continued fire. Ore which has been roasted must be red, friable, and porous. When black and magnetic, it is converted into magnetic ore, and will not smelt grey iron. When it has been too hard burned, it should be thrown aside, or mixed with well-roasted ore in certain proportions. When white iron for the forge is to be smelted, little attention is required in roasting the ore; still that from roasted ore works better in the forge, and forms a stronger iron.

Fluxes.—In practice we are limited to a few minerals as flux—limestone or chalk for silicious ore; and silicious clay, or other silicious compounds, for calcareous ore. When either lime or silex is in excess in any ore, the work in the furnace is imperfect; much coal is used, and labour wasted. One of the first maxims in selecting flux should be that it contains an admixture of iron; and if such cannot be obtained, which is most frequently the case with limestone, an impure is preferable to a pure limestone. The leading principle in all smelting operations is, to smelt by as low a heat as possible. The oxidized elements which enter an iron blast furnace do not melt by themselves, at least not at a low heat; a mixture, and an intimate mixture of ore and fluxes, is the most profitable condition under which smelting may be carried on. If these conditions cannot be realized absolutely, because it would be too expensive, they ought to be present to the mind of the smelter at all times, and his endeavour must be to approach them. Limestone does melt, but not pure lime; limestone mixed with silex melts more readily than when pure, and still more so when clay is present; and at a lower heat still when iron also is added. An ore which contains all the elements requisite to melt at a moderate heat, and still is easily fusible after the metal is removed, is in the best form of ore; it works with the least fuel. If the latter condition is not complied with, or the residue of the ore fusible, it belongs to the refractory kind, and is expensive in smelting. The true theory of smelting is, to fuse the metal first, and remove it from the ore at a lower heat than that at which the impurities melt. All the metal should be removed before slag is formed. When these conditions are complied with, and the slag melts at a moderate heat, smelting goes on most profitably. In practice it does not happen very often that ores which act in this manner are found, at least not in large quantities. Bog ores, yellow and brown hematites, are sometimes found of a suitable composition. In the State of New Jersey, U.S., at Andover, a primitive ore is mined and smelted which affords flux in its own composition. These ores prove in practice the correctness of the above statements. Fluxes, of course, do not always consist of the same substance. If silex is the predominating or only foreign matter in the ore, limestone must be the flux; and limestone which contains clay, like some of that in the coal formations, is preferable to pure or silicious limestone. If lime is present in the ore, and if it is the cause of resistance to fusion, silex or silicious rock containing clay must be added in order to smelt the ore perfectly. Clay ores, such as frequently occur and are mined in the coal formation, do not work so well with pure limestone as with a silicious limestone. Iron, when present in these fluxes, no matter if they are limestone, slate, shale, or clay, has a beneficial influence; because it is in small quantities which cannot easily be removed, it causes the flux to melt and float down until it meets the ore, upon which it will settle and with which it will combine. It is easily perceived that when an incongruent mass of various infusible substances is brought in contact, it will require a long time, and consequently much fuel, before they are united. In all cases, one of the ingredients in the furnace ought to be fusible at a moderate heat. Blast-furnace slags, especially the white and grey varieties, have been used upon emergency as fluxes for ores free from gangue, or ores containing much silica.

The limestone used as flux is usually charged into the furnace in the state in which it comes from the quarry, the preliminary operations being limited to reducing the dimensions of the blocks, that calcination may be the more readily effected. In a few establishments, however, the stone is calcined in kilns, by which the water and carbonic acid is expelled, and lime obtained in the caustic state. This process is performed in kilns, of the construction employed for the calcination of ores, and is conducted throughout on nearly similar principles.

Amount of Fluxes.—On the amount of fluxes not much can be said; a certain proportion of every principal constituent in the mixture of ore and flux is advantageous. The average of a good composition of furnace slag is nearly 40 silica, 20 lime, 12 alumina, 12 magnesia, and some oxide of manganese and oxide of iron; there are, however, others which answer equally as well. This is altogether a practical subject, so far as particulars are concerned. No slag, or composition of ore and flux, can be determined *a priori*, nor with the assistance of the best assays of all the minerals in composition. We may come very near to the true composition, but not always to the definite quantities. Purely silicious ore requires more limestone than that which contains

silex and clay. Smelting by mineral coal occasions the use of more lime than smelting by charcoal; and by impure coal more than that coal which is not much adulterated with ashes. Fluxes should be broken into equal fragments of 2 in. for charcoal, and 3 to 4 in. for anthracite coal or coke.

Mixing of Minerals.—In order to ensure regular and economical work in a furnace, the minerals should be mixed in certain proportions, according to the quantities of each kind which are at disposal. In this instance, as in others, it is true that the greater the number and variety of elements, the more prosperous will be the work. Six kinds of ore work better when mixed together in a furnace, than two kinds. One kind of ore does not work well; it requires much coal, and is vexatious to the smelter. In mixing the ore a certain quantity—say fifty wheelbarrowfuls —are spread on a level floor in the bridge-house, in a stratum of uniform thickness. Upon this a stratum of a second kind of ore is spread; then a third, fourth, &c., all in ratio to the mixture calculated. On the top of this bed of ore, the flux is levelled in the necessary proportion. From this bed a charge, ready mixed, is weighed as it is wanted. At many furnaces this important part of the business is often left to careless hands, who take a certain quantity of ore from each kind, also some flux, and charge that into the furnace promiscuously. On the same principle that many kinds of ore work better together than each singly, and on the principle that the close contact of various particles of matter causes them to unite, or melt, at a lower degree of heat than when farther separated; for these same reasons the ores ought to be well mixed. It should not be placed in the furnace in heaps—that is, a wheelbarrowful of magnetic ore in one part, and half a barrowful of hematite in another place, and thus with the other kinds. If the fragments of ore and flux are all of the same size, the rule in mixing them must be, to associate together a certain number of pieces of each kind of ore, and add its ratio of flux. A charge composed of such uniform parcels we may call a unit of the composition.

Fuel.—Charcoal was at one time exclusively used in the smelting of iron; it is of great value in making the best descriptions of iron, and it is still in use in many parts of the world, especially in the United States, Russia, and Sweden. In Great Britain coal is now the only fuel used with iron, there being in 1871 but one furnace smelting hematite ores with charcoal.

Before the introduction of the hot blast the coal was generally converted into *coke*, to assimilate it as much as possible to the original and better material. But the hot blast has enabled iron-masters to dispense in many cases with the coking process, and to use raw coal in the furnaces. The quality of the iron has, however, suffered by the change, as the sulphur and other deleterious ingredients, which are partly eliminated by the process of coking, remain fully present in the furnace when raw coal is used.

It is only certain sorts of coal that are found suitable for use raw; others have been tried, but failing to give satisfactory results, the coking process has been retained.

Blast Furnaces.—We have already, in the article BLAST FURNACE, described the construction and application of these important appliances. However, the following details and description of the erection and working of two blast furnaces at Newport, near Middlesborough, taken from a paper read before the Institution of Civil Engineers by Bernhard Samuelson, merit particular notice.

The ores, the fuel, and the flux are charged as usual at the top of the furnace, in proportions varying according to their chemical constituents and mechanical condition, and according to the greater or less perfection of the furnace and of its accessories. Air is blown in through tuyeres at the hearth, scoria flows over the dam, and the iron is allowed to run from the tapping hole at proper intervals. Economy in smelting is sought in a diminished expenditure of fuel and flux, and of labour in producing a ton of iron from a given weight of iron ore, and is promoted in the first place in all ores containing much moisture or carbonic acid, or both, by their perfect calcination before they are charged in the furnace. Secondly, by the proper coking of the coal, where it is too bituminous, or too liable to decrepitate, to be used raw. Thirdly, by heating the air before it is introduced into the furnace, so that a very high temperature may be created in the zone of fusion, immediately above the tuyeres. And fourthly, by durability and simplicity of construction of the entire plant, in order to ensure the utmost constancy and regularity in working.

The ironstone smelted in Cleveland is the argillaceous ore from the lias, containing when dried from 33 to 40 per cent. of protoxide of iron, and from 2 to 7 per cent. of sesquioxide of iron, equal to 26 to 33 per cent. of metallic iron, which percentage is increased in calcined ironstone to from 37 to 40 per cent. by the moisture and part of the carbonic acid being removed by calcination.

The raw stone also contains

From	20 to 25	per cent. of	carbonic acid.
„	3 to 4	„	magnesia.
„	5 to 8	„	lime.
„	10 to 15	„	silica.
„	10 to 15	„	alumina, and
„	1 to 1½	„	phosphoric acid.

The fuel is the coke of South Durham, yielding

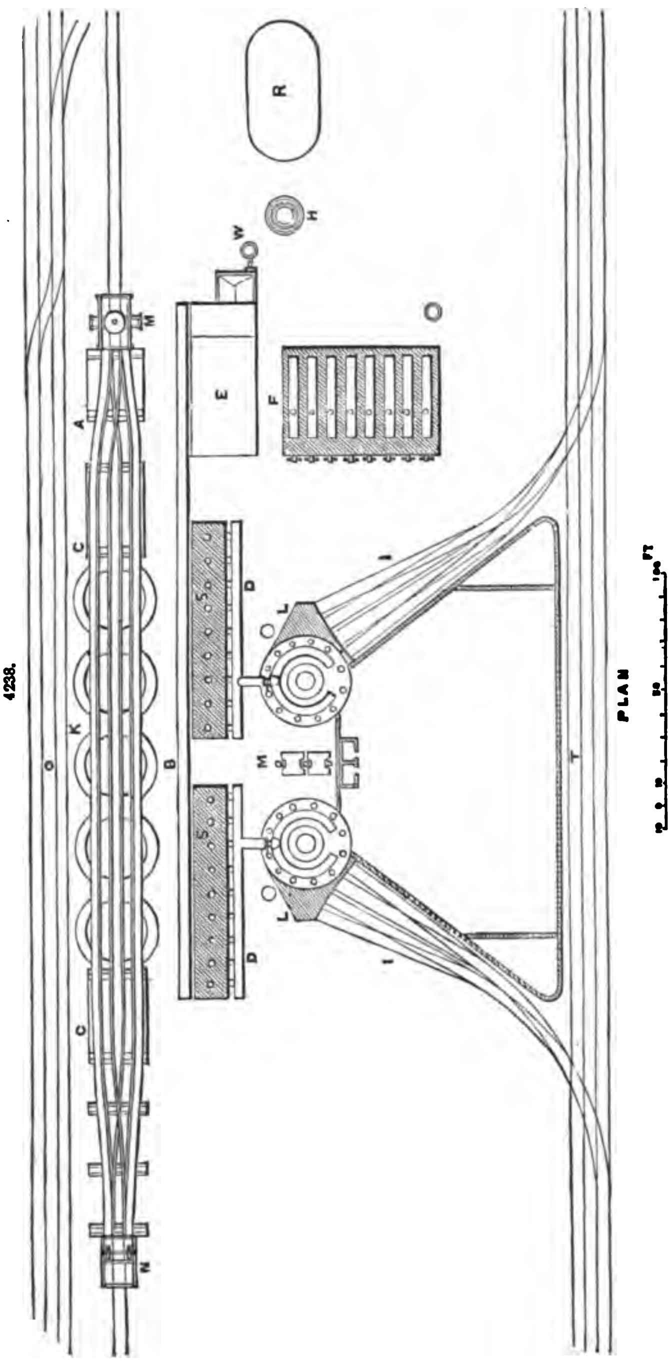
From	85 to 92	per cent. of	carbon,
„	½ to 2	„	sulphur, and
„	4 to 12	„	ash.

The flux is raw or burnt limestone, chiefly from the Pennine range, containing in the raw state from 87 to 96 per cent. of carbonate of lime.

The fuel and limestone consumed, in order to produce a ton of grey foundry pig iron from Cleveland ironstone, without admixture of foreign ores or of the cinder from rolling mills, are from

19 to 28 cwt. of coke, and from 10 to 14 cwt. of limestone, the figures varying with the fusibility and richness of the ore, the quality of the fuel and flux, the heat of the blast, and the capacity and regularity of working of the furnaces. In one of the furnaces, the average consumption of fuel, excluding the six weeks immediately after blowing in, has been 20·35 cwt. to the ton of iron produced; the minimum quantity used in any one week 18·78 cwt. the ton of iron, and the maximum quantity 22·12 cwt. the ton of iron. The average quantity of calcined ironstone used has been 46·11 cwt. the ton of iron; the minimum quantity used in any one week 44·16 cwt. the ton of iron, and the maximum quantity 48·04 cwt. the ton of iron. The average quantity of limestone used has been 10·71 cwt. the minimum quantity in any one week 10 35 cwt., and the maximum quantity 11·26 cwt. the ton of iron. The average weekly produce of pig iron was 430 tons, the maximum 500 tons. These quantities of coke and flux are about 15 per cent. less than those of five other furnaces erected in 1863–64, in which the same materials are used; but the internal capacity of which, 16,000 cub. ft., as against 30,000 cub. ft., is less in the proportion of nearly 1 to 2 than those being described, the heat of the blast being nearly the same.

4238.



The quantity of coal used in the kilns, in calcining the ironstone and limestone producing a ton of iron, is 3·94 cwt. With a regular supply of ironstone 3·50 cwt. is sufficient.

Fig. 4238 gives a ground plan of the works. A is a coal bunker; B, cold-blast main; C C, coke bunkers; D D, hot-blast mains; E, engine-house; F, boilers; H, chimney; I I, slag roads; K, kilns; L L, furnaces; M M, hoist; N, drop; O, mineral sidings; P, pig beds; R, reservoir; S S, stoves; T, metal road; W, well. The whole of the raw materials, which are received in trucks, of which the gross weight varies from 10 to 17 tons, enter at the east end of the works, and descend by gravity to a steam lift, which raises them to a gantry surmounting a series of calcining kilns and coke boxes. The trucks have movable bottoms, and the ironstone, limestone, and coal, used in calcining, are discharged from them into the kilns in proper proportions. The coke is allowed to fall into the

boxes or bunkers, having hoppers and slides at the bottom, on opening which the coke falls into barrows, ready for charging in the furnaces. The calcined ironstone and burnt limestone, when withdrawn from the kilns, are likewise raked into barrows. The trucks when emptied descend by the drop, and are run into sidings ready for removal from the works. The barrows are raised to the tops of the furnaces by the steam lift. The slag flows from the furnaces into slag boxes or bogies, and is removed by a locomotive engine. The pig iron is tapped from the furnaces four times in every twenty-four hours, and is loaded on trucks from the pig beds. These trucks leave the furnaces by a railway in the opposite direction to the one by which the materials enter, joining the main line of the North-Eastern Railway at the western side of the works, where there is also a private wharf on the river Tees, forming part of the works, at which vessels of from 600 to 800 tons can take in their cargoes. All trucks, whether full or empty, enter at one end, and leave at the other, by which means the greatest economy of labour and time in working the traffic is secured.

The blowing engines, four in number, are placed in the engine-house at the east end. The series of eight boilers for supplying steam to those engines, to the steam-cylinder for lifting the trucks, and to the small engine which works the hoist, are placed as shown. The blowing engines all communicate with the horizontal cold-blast tube, whence the air is distributed to the stoves, in which it is raised to a temperature of 1250°, sufficient to give a heat of 1100° at the tuyeres; it is then discharged into the hot-air main, and thence through the tuyeres into the furnaces.

The furnaces are closed at their mouths by a bell and hopper (cup and cone), and the waste gas, instead of as formerly burning at the tunnel-head, is withdrawn by the vertical tubes to an underground brick culvert, from which branches run to the hot-air stoves and to the boilers. Just before adding a fresh charge of materials the temperature of the gas is upwards of 600°, and descends nearly to 300° when the charge has been introduced. As, temperatures of gases taken at top of No. 6 furnace;—

11.0	A.M.	315°, charge just lowered.
11.15	„	436°
11.30	„	634°
11.40	„	335°, charging furnace

The combustion of this gas heats the stoves and raises steam in the boilers, so that no coal is consumed for either of these purposes, except in cases of stoppage. The entire consumption of coal in twenty-six weeks, exclusive of that used in first lighting up and in calcining, has been 190 tons, or $7\frac{1}{4}$ tons a week.

The number of men employed about the two furnaces in twenty-four hours, exclusive of mechanics for repairs and platelayers, but including enginemen for removing the slag, is seventy-seven—fifty-two in the daytime, and twenty-five at night; being one man for every 11 tons of materials of every kind, including slag, transported; or one man for every $1\frac{1}{10}$ ton of pig iron produced.

A weighing machine is placed at the entrance of the works, for weighing the raw materials as they arrive. The pig iron is weighed on leaving the works, along with that of the other furnaces, at a point which is not included in the plan.

Commencing at the point where the raw material enters the works, the first operation, as before stated, is to lift it to the level of the kiln-gantry, or stage. The average weight of a loaded truck is about 14 tons, and the trucks are lifted 40 ft. The hoist for effecting this operation is shown in Fig. 4239. It consists of a steam-cylinder A, supported on columns, furnished with a piston and piston-rod, to the lower end of which is attached the cross-head of the cage B. The loaded trucks are allowed to enter the cage by a gentle descent. The steam is then admitted to the under side of the piston, and the load is lifted by the upward pressure of the steam to the higher level. The diameter of the steam-cylinder is 38 in., and its length is of course equal to that of the lift. As will be noticed, the cylinder is built in sections and bolted together with flanges, each flange being faced with a rebate so as to secure an accurate fit. There is no difficulty in boring out all the sections perfectly parallel. When the truck is removed at the top, the cage is made to descend again by exhausting the steam. This, however, is not allowed to take place directly into the air, but through the pipe C to the upper side of the piston. The latter is thus kept warm by being at all times filled with steam; any entrance of air being prevented by the valve D, which opens outwards. The actual exhaust takes place during the next upward stroke, when the steam on the upper side of the piston is pushed, along with any condensed water, through the valve D, after which it passes by the pipe E to the cooling reservoir, joining the waste tuyere-water in its way, so that the steam is entirely condensed. It will be perceived that this form of hoist precludes the possibility of economizing to any great extent by expansion. Its great simplicity, however, as well as its effectiveness and perfect ease in manipulation, are advantages which outweigh other considerations.

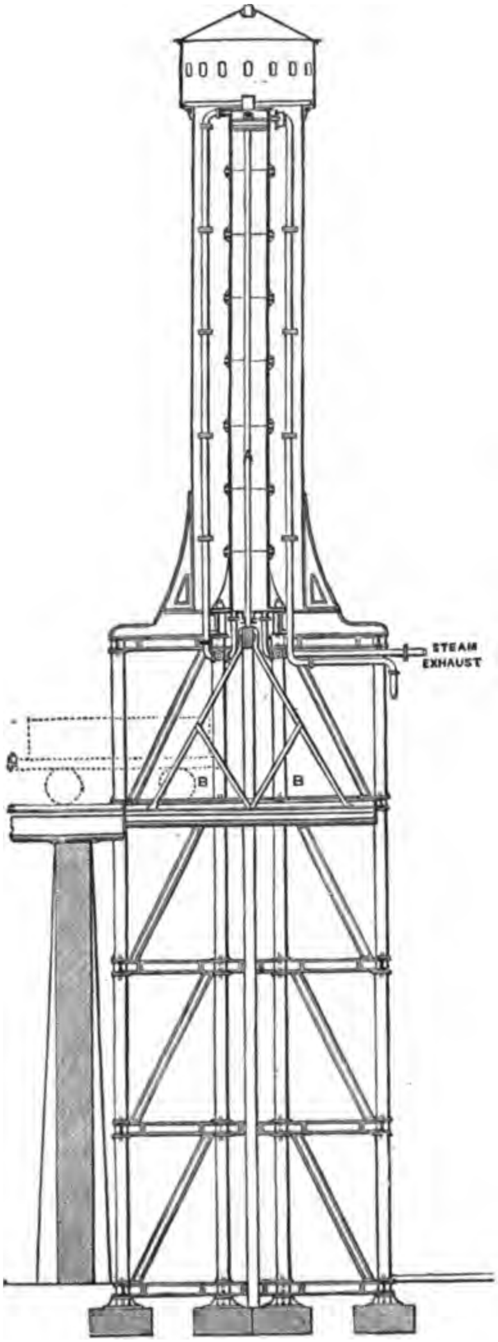
The truck of raw material having been thus lifted, and having discharged its load into the kilns or bunkers, as the case may be, is passed on to the other end of the gantry, and lowered again to the ground level by the drop shown in plan, Fig. 4238. This drop may be briefly described as a friction-brake apparatus, supported on cast-iron columns. A platform, suspended by wire ropes which pass round pulleys, is keyed on to the same shaft as the brake wheels. The pulleys are provided with counterbalance weights, which outweigh the platform, and thus tend to keep it always at the top. When an empty truck is pushed on to the platform the balance is destroyed, and the truck is allowed to descend gently by means of the brake handle.

All the raw materials having been lifted, as described, the ironstone, along with the limestone and small coal, is tipped into the kilns, and the coke into the boxes. These latter are constructed of wood, and are two in number; each capable of containing 250 tons of coke. The flooring of each box is about 6 ft. from the ground, and is provided with four sliding doors, through which

the coke is shot into barrows as it is required. Besides these coke-boxes, there is also an additional box next to the lift for storing small coal for the use of the kilns. The flooring of this box is high enough to admit a railway wagon underneath, so that, should the daily supply of small coal fall short, the kilns may be replenished from this source with the least amount of labour.

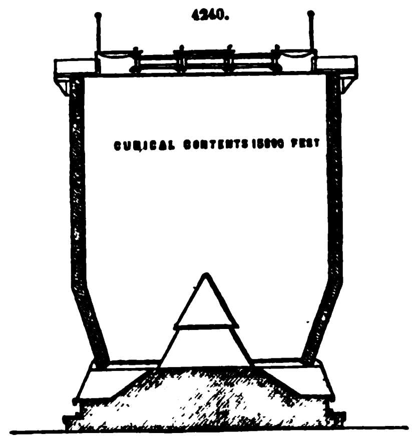
The kilns are five in number, and sections of one of them are shown in Figs. 4240, 4241. It consists of an outer cylindrical shell of wrought iron, varying in thickness from ⅜ of an inch at the bottom to ¼ of an inch at the top, and an inner lining of fire-brick, 12 in. thick. The interior diameter of the kiln is 26 ft., and it is tapered inwards at the bottom. There is also a central cast-iron cone, with its apex upward; the object of which is to hold up the charge and at the same time guide it conveniently towards the openings, out of which it is ultimately drawn. Each kiln has eight of these openings ranged round its circumference; and they serve both for drawing the charge as it comes down calcined, and for admitting the air for combustion in calcining. The capacity of each kiln is 15,800 cub. ft., representing

4239.

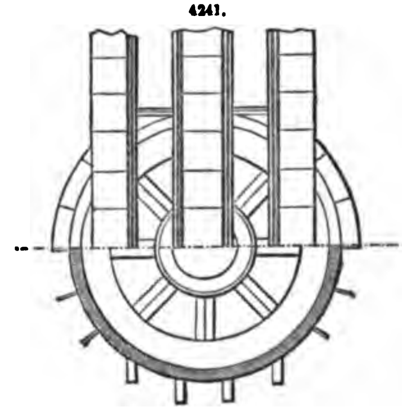


SCALE ⅜ OF AN INCH TO 1 FOOT

4240.



4241.



630 tons of mixed materials. In these works, although not always the case elsewhere, the limestone is tipped into the kilns along with the ironstone, by which means it is thoroughly dried and semi-calcined.

The next process is to remove the materials to the furnaces. Each barrow, for this purpose,

when filled, is passed over a small weighing machine, and is then wheeled on to the cage of the furnace-hoist. The entire lift to the charging platform of the furnaces is 92 ft., and the construction of the hoist is shown in Fig. 4242. In this case, the moving power, instead of being below as usually arranged, is placed overhead, and consists of a double-cylinder engine, with valves worked by link-motions. The diameter of the cylinders is 8 in., and the length of stroke 12 in. On the crank-shaft are two pinions working into two wheels on an intermediate shaft. At the middle of the latter shaft is keyed a larger pinion, gearing into the main spur-wheel A, which is 12 ft. in diameter. Each side of this spur-wheel is flanked by a grooved pulley, carrying a steel rope $1\frac{1}{4}$ in. in diameter. The ropes are made to fit the grooves with exactness, and they only pass half round their respective pulleys, the ends being attached in pairs to the two cages B B. Thus, while one cage is going up, the other is going down; and the work is done entirely by the friction of the ropes in their grooves. In order to secure equal tension on both ropes, the attachment to the cage is by a double lever, similar to a balance-beam, which immediately yields to any unequal stretching of the ropes. The cages are steadied in their ascent and descent by guides attached to the columns C, which support the platform. The average weight raised at each lift is about 2 tons, although much more is capable of being lifted without the ropes slipping. It will be perceived that the moment the descending cage reaches the bottom, the strain on the ropes is relieved, so that they will no longer hold sufficiently in the grooves to enable the ascending cage to rise any higher. It follows that overwinding cannot possibly take place. The length of steam-pipe required for working the engine at this elevation is found unobjectionable in practice. The entire length of pipe from the boilers is 200 ft., and it is well covered with non-conducting material. The engines are usually worked at about 150 strokes a minute; and calculating for loading and unloading the cages, they are capable of making one lift a minute; and of thus raising in the hour 120 tons of material.

4242.

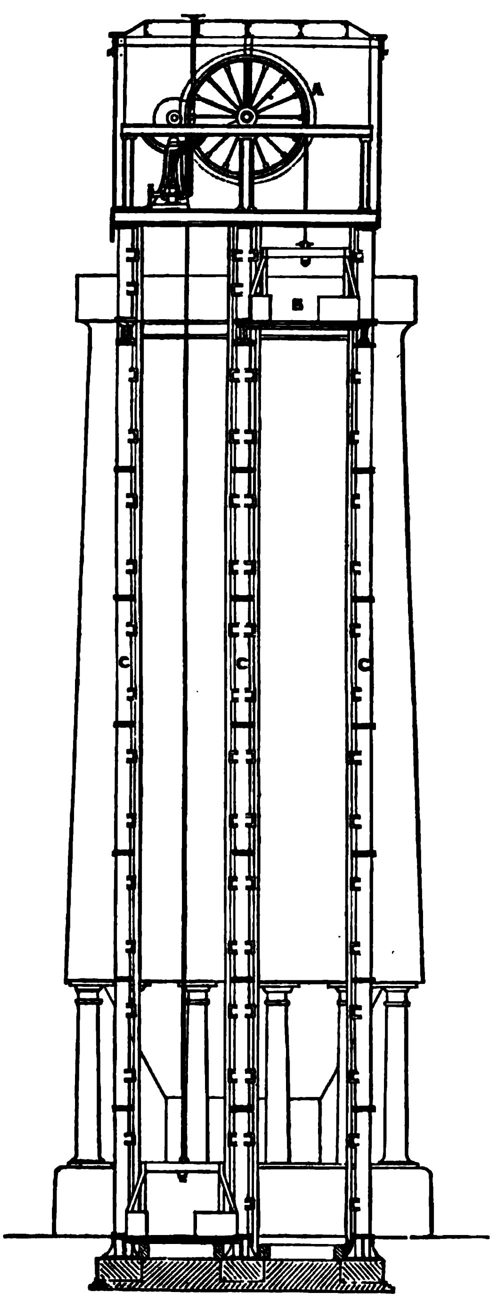
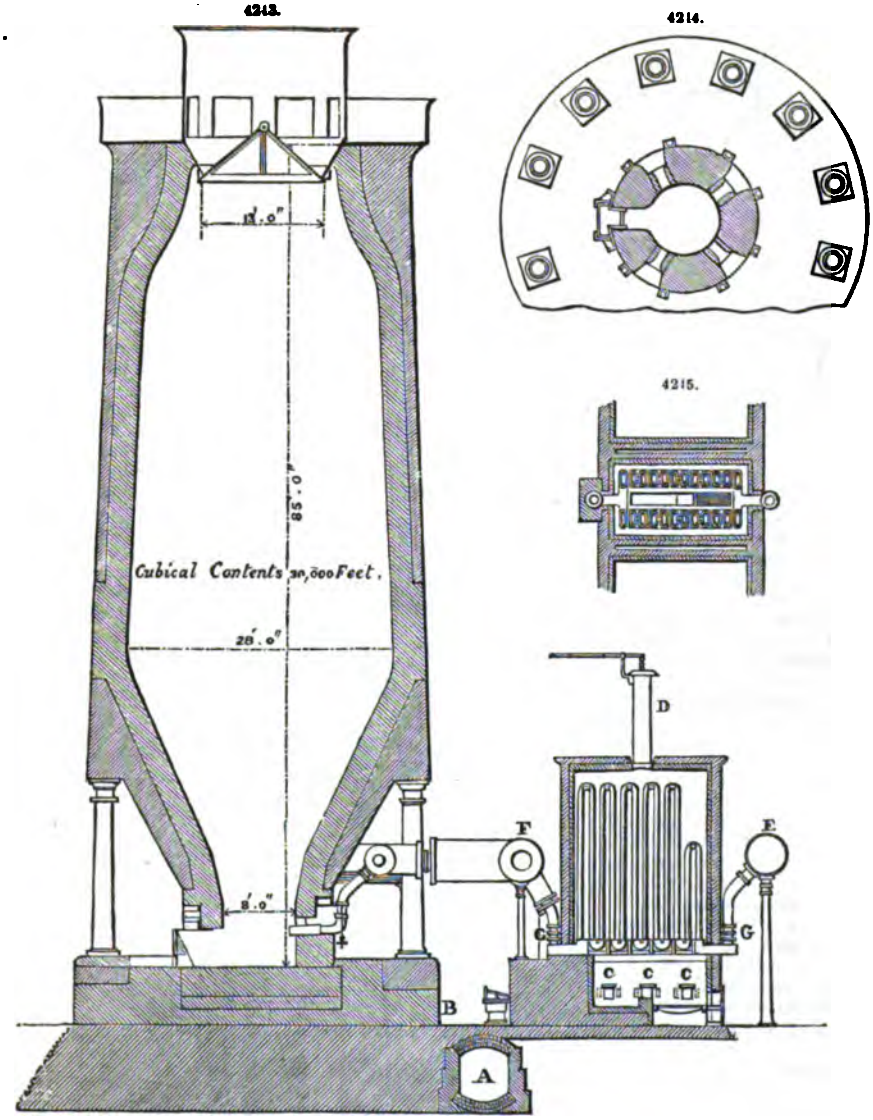


Fig. 4243 is a vertical section of one furnace. The foundation up to the ground level consists entirely of brickwork resting upon clay. From this point a circular base is carried to a height of 7 ft. in solid brick-work, mainly of fire-brick, with a stone curb all round, on which the supporting columns rest. These columns are 18 ft. 6 in. in height, averaging 2 ft. 4 in. in diameter, with a thickness of metal of 2 in. They serve to support the structure from the angle of the bosh upwards, the lower part being carried partly by the wrought-iron conical casing, and partly by the brickwork and stanchions which surround the hearth. The whole of the furnace from the tuyeres upwards is cased with wrought-iron plates, those of the lower or conical part being $\frac{1}{2}$ in. thick, while those of the barrel vary from $\frac{7}{16}$ of an inch below to $\frac{3}{8}$ of an inch at the top. The interior of the furnace is lined throughout with fire-brick lumps 5 in. thick, and of dimensions varying with the internal diameter, no two courses being alike. The backing between the inner lining and the shell is of ordinary fire-brick. Up to a short distance above the tuyeres every fire lump is chisel-dressed on both beds and joints, and the same is also the case with the hearth lumps, which consist of two courses set on edge and breaking joint; the lower course being 18 in. deep and the upper one 3 ft. The following are the principal dimensions of the furnace;—

Diameter of the hearth, 8 ft.; depth at tuyere, 3 ft. 6 in. Diameter at the bosh, 28 ft. Diameter of the bell-opening, 13 ft. Total height from the hearth to the platform, 85 ft. The cubical capacity is 30,065 cub. ft. There are four tuyeres, Fig. 4244, each with a muzzle 6 in. in diameter, and

4243.



4244.

4245.

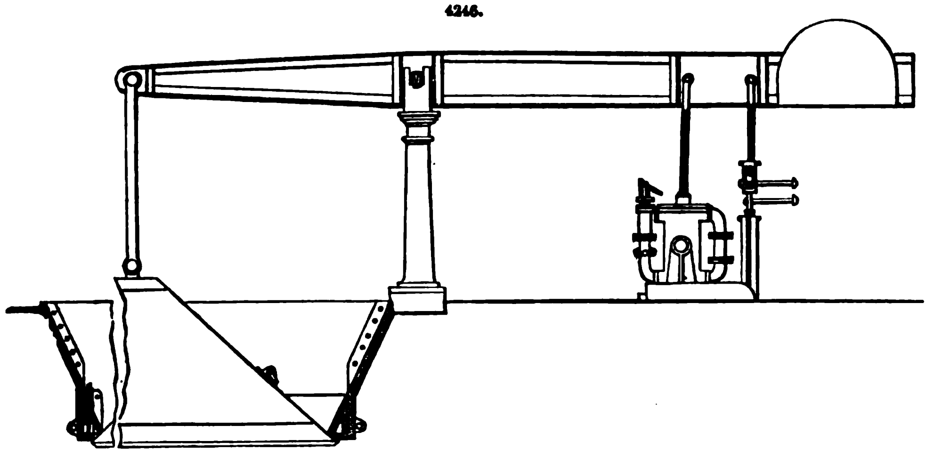
the dam-opening is 2 ft. wide. The pig-beds are necessarily of large dimensions, being capable of holding 1200 moulds for each furnace. The slag-boxes are eight in number, and large enough to contain upwards of 3 tons of slag each.

The construction of bell and hopper for charging the furnace is shown in Fig. 4246. It consists of a bell suspended from a lever, having at its opposite end a counterbalance weight sufficient to keep it closed when not loaded with the charge of materials. The lever is connected to a piston in a small cylinder filled with water, having a passage by which the water can flow from one end of the cylinder to the other. So long as this passage remains closed the whole apparatus is immovable. Six barrow loads of material are tipped into the hopper, and rest upon the bell. A catch is now released, and opens the passage between the top and bottom of the cylinder. The lever is no longer held by the piston, which is able to move upwards in the cylinder. The weight of the bell and charge together overcomes the counterweight; they descend, and the materials fall into the furnace. As soon as they are clear of the bell, the counterweight preponderates, the bell rises again, closing the furnace, whilst the piston descends and forces the water back through the passage from the bottom to the top of the cylinder. The passage is then closed, and the apparatus

is ready for the next charge. This form of lowering apparatus is the invention of Mr. Wrightson, of the firm of Head, Wrightson, and Co., Stockton.

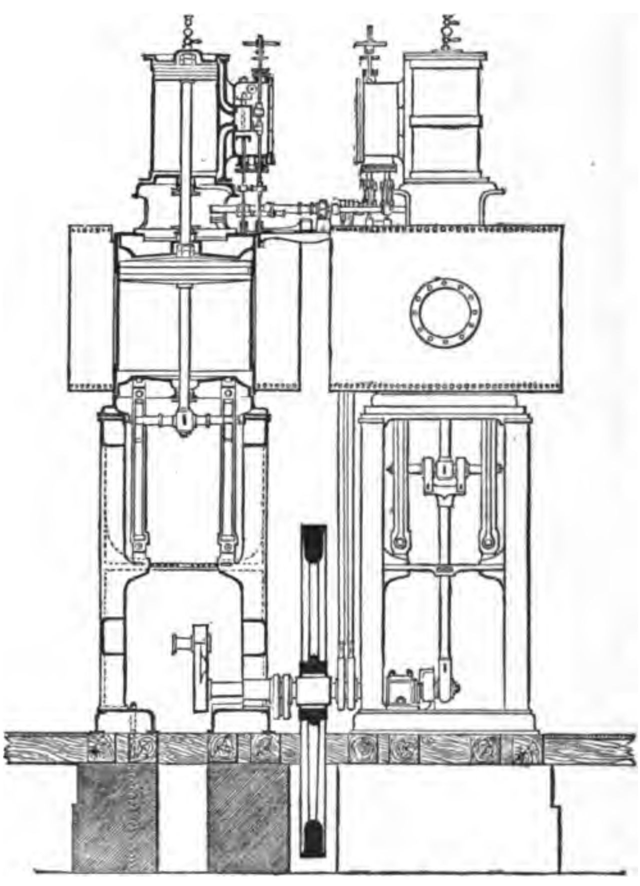
In each furnace, the average consumption of air, of the density of the atmosphere, is about

4246.



8000 cub. ft. a minute, but it leaves the blast cylinders at a pressure of 4·5 lbs. on the square inch above the atmosphere. This pressure is reduced to 4·25 lbs. by passing through the heating stoves, and finally to 3·75 lbs., by the time it reaches the tuyere most distant from the blowing cylinders.

4247

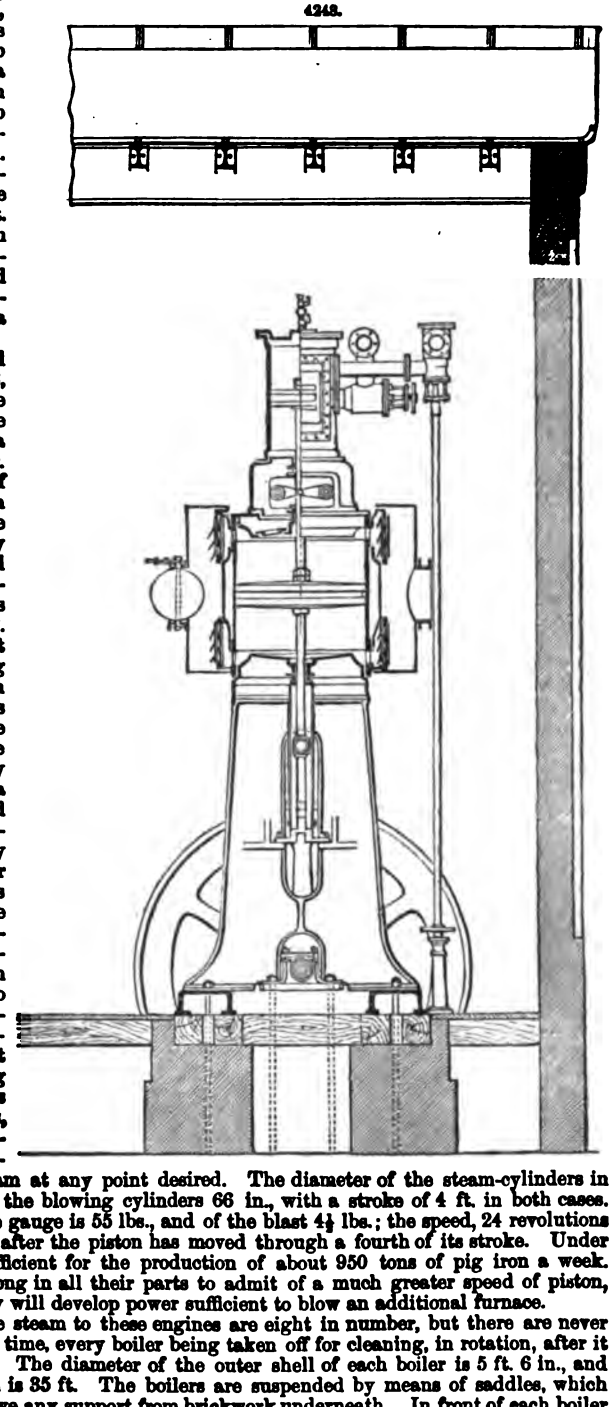


The charge gradually descends to the zone of fusion, whilst the gaseous products of combustion, sufficiently charged with carbonic oxide to be themselves combustible on coming into contact with air, ascend. The top of the furnace being closed, the gas escapes through an opening at the side and descends the wrought-iron main or down comer, which is 6 ft. 6 in. in diameter, into an underground brick culvert. This culvert traverses the entire length of the stoves and boilers, each of which is furnished with a branch-flue and valve, so that each may obtain its share of gas according to its requirements.

The stoves for heating the blast consist of nine sections for each furnace, eight being always in action at one time, while one in rotation is allowed to cool for the purpose of cleaning. Figs. 4243, 4245, show the interior of one section. The gas is introduced by the valve B into the lower chamber, where it meets the air which enters by the openings C C. The gas and air being here thoroughly mixed, the flame arising from combustion plays among the cast-iron pipes, and issues by the chimney D. The blast enters the pipes from the cold-blast main E on the right, passing up and down until it reaches the hot-blast main F on the left. The latter is lined with

brickwork 14 in. thick in order to prevent radiation, and from it the air is distributed to the various tuyeres by the shortest possible route, every precaution being taken to prevent loss of heat by surface cooling. The heating pipes are ⋂-shaped in elevation, and oblong in cross-section, as shown in plan. There are two rows in each section, six in a row, and they lean against each other at the crowns in order to force the flame to circulate between and at the back of them. The total internal heating surface of all the sections for one furnace is about 10,000 sq. ft. In addition to the gas-valve each section is furnished with blast-valves G G, both on the hot and cold sides, so that it can be entirely isolated from the rest at a moment's notice.

4248.



The cold-blast main, as will be seen in the plan, Fig. 4238, takes its commencement at the back of the engine-house, there being a branch furnished with a valve from each blowing cylinder.

The blowing engines are of the vertical construction, which has become so general in the Middlesborough district. They are four in number, but coupled in pairs, each pair having a fly-wheel between them, with cranks at right angles, Figs. 4247, 4248. The object of this arrangement is to give facility for carrying out the principle of expansion to a greater extent than is usually done. The resistance being direct and constant, there is in a single engine a difficulty in turning the centre under a high degree of expansion, and consequently of varying pressure, except with an unusually heavy fly-wheel. When a pair of engines is coupled, as in this case, the power throughout the stroke is equalized so as to admit of a higher degree of expansion. The steam is cut off by an additional eccentric working two plates on the back of the ordinary valve, and the grade of expansion can be altered without stopping the engines by turning the wheel at the top, which acts on right and left handed screws, so as to cause the plates to approach or recede from one another, and thus cut off the steam at any point desired. The diameter of the steam-cylinders in these engines is 32 in., and of the blowing cylinders 66 in., with a stroke of 4 ft. in both cases. The pressure of the steam at the gauge is 55 lbs., and of the blast $4\frac{1}{4}$ lbs.; the speed, 24 revolutions a minute. The steam is cut off after the piston has moved through a fourth of its stroke. Under these conditions the blast is sufficient for the production of about 950 tons of pig iron a week. The engines are sufficiently strong in all their parts to admit of a much greater speed of piston, and by working less expansively will develop power sufficient to blow an additional furnace.

The boilers for supplying the steam to these engines are eight in number, but there are never more than seven working at one time, every boiler being taken off for cleaning, in rotation, after it has been in work fourteen days. The diameter of the outer shell of each boiler is 5 ft. 6 in., and of the flue 2 ft. 9 in.; its length is 35 ft. The boilers are suspended by means of saddles, which span the top. They do not derive any support from brickwork underneath. In front of each boiler is a combustion-chamber made of fire-brick, and into this the gas is first admitted from the gas culvert by valves, the air being allowed to meet it by a concentric perforated pipe fitted with a regulator. The water for feeding the boilers is heated by the exhaust steam to about 200°, and the

feed is effected by two donkey-pumps, each having two plungers 4 in. in diameter; one pump being sufficient to do the work in case the other requires repair. The burning gas, on leaving the combustion-chamber, passes through a tubular flue and returns underneath the boiler to the front end, and thence by the smoke flue to the chimney.

The feed-pumps are situated in the small building attached to the engine-house; and here also are placed the tuyere-pumps, of which there are two, each with double plungers 10 in. in diameter. They draw water from the well, and pump it into the tank which forms the roof of the engine-house. From this tank the water distributes itself by gravitation to the various tuyeres, and then returns to the cooling reservoir, and from this again to the well, thus keeping up a constant circulation. The waste from evaporation and other causes is replenished from the water mains with which the town of Middlesborough is supplied. The time occupied in the construction of the works was fifteen months.

For working the traffic of these furnaces, and removing the slag, two locomotives are required. The former has cylinders 12 in. in diameter, with a stroke of 16 in.; the latter has cylinders 9 in. in diameter, and a stroke of 12 in. As the traction is occasionally heavy, the wheels of the smaller engine are small (2 ft. 6 in. in diameter), and the tread is short (5 ft.), in order to enable it to turn round curves of small radius. Locomotives employed for this purpose, not requiring great speed, have been usually geared after the manner of traction engines; but the new construction is found to do better, and without the same liability to get out of order.

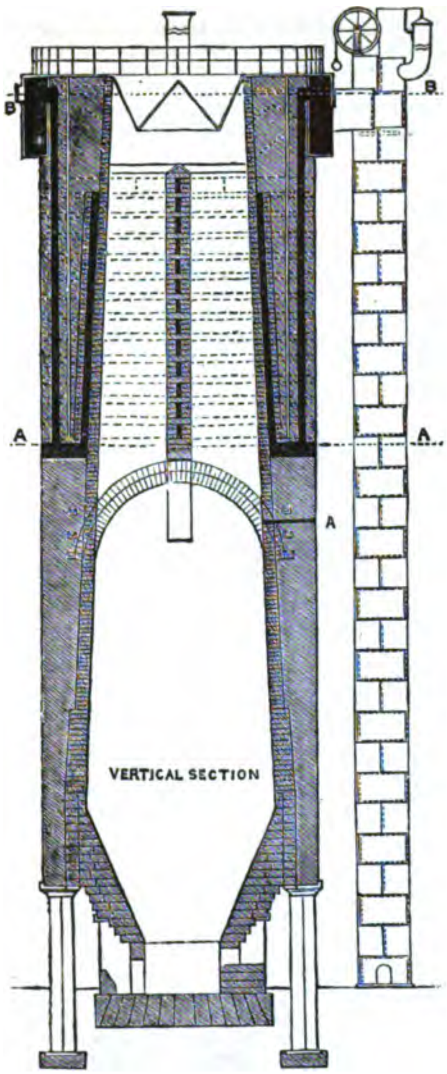
A self-coking blast furnace, Figs. 4249 to 4252, of peculiar construction, has recently been erected by William Ferrie at the Monkland Iron-works. The fuel is charged in the raw state, under an ordinary bell and cone appliance. The height of the furnace is 83 ft., diameter at bosh 18 ft., and width at the top 12½ ft. The top is closed by the bell and cone, and the gases are led to heaters in the usual way. The upper part of the furnace, below the space required for bell and cone, and terminating 20 ft. lower down, is divided into four compartments or retorts by vertical walls, supported on arches and radiating from the centre. These vertical walls, and also the circumferential walls, are pierced with flues, through which a portion of the gases, taken from the top, are led as far down the interior of the furnace as the bottom of the retorts. The gas so conducted, after being mixed with the necessary quantity of atmospheric air, which is admitted by means of gratings placed round the outer stem of the furnace, is ignited and passes up through and around the flues, and is assisted in its passage by stalks attached to top of furnace. The brickwork on each side of vertical walls is 9 in. thick, and that between inside of retorts and flues in circumferential walls is also 9 in. The temperature in all the flues will range from 1500° to 1700° Fahr. The heat in brickwork forming the flues is a bright red, which passing through the 9-in. walls, and combining with the ascending heat from the lower part of the furnace, completely cokes the coal in its passage down the four retorts or compartments, and at the same time, and in the same way, it raises the temperature of the ores and flux to the same degree. In proof that the materials are at the temperature stated, a hole was drilled, at the request of I. Lowthian Bell, through the wall of the furnace at point A on Fig. 4249, about a level with the spring of the arches on which the retorts partially rested. The burden as seen through this opening was at a bright red heat, and the temperature, taken by means of Siemens' pyrometer, 6 in. from inside of lining, was at one reading 1434°, and at another 1554°. The gases passing out of this opening were of a pale blue colour, indicating that the fuel at that zone had parted with its principal gaseous components, and was in a state of coke.

The results obtained from this furnace have been most satisfactory, in regard to not only effecting a saving of coal and ores, but in superior quality of iron produced. In the Lanarkshire district, the quantity of coal required in the manufacture of a ton of No. 1 pig iron ranges from 50 to 52 cwt. in the furnace, whereas in this furnace a ton of the same quality can be produced with 32 to 36 cwt., effecting a saving of nearly a ton of fuel to the ton of iron made. In ores, the saving in this furnace will be about 2¾ cwt. the ton of iron. One explanation of this saving in ores, writes William Ferrie, in the Journal of the Iron and Steel Institute, is, that they break into powder a few feet down the furnace, and are blown out at the furnace top, as is the case with coal, where no less than 81·54 per cent. of its available properties, in the process of smelting, escape as waste at the furnace top.

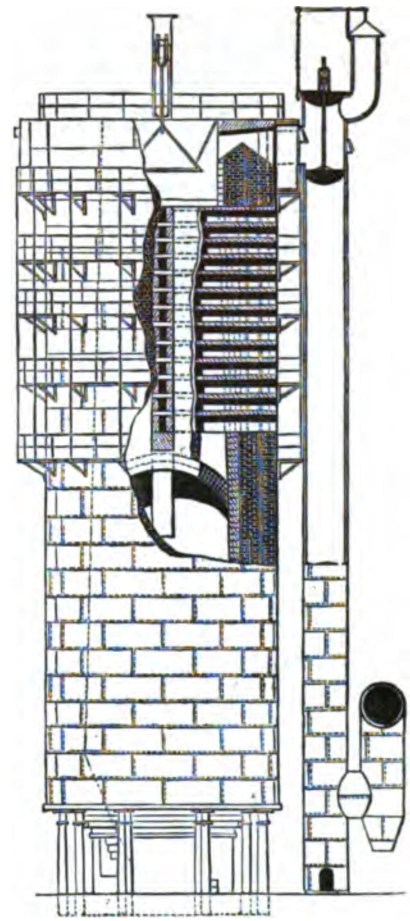
I. Lowthian Bell, the eminent and scientific ironmaster, states that practically in the blast furnace the whole of the work is done, not by raw coal, but by coke, and the advantage of using raw coal instead of coked coal is, that the loss of carbon which takes place in the ordinary coking oven is entirely saved in the blast furnace when coal is used. There is also a small saving of the wages and labour connected with coking the coal, and also a very large production of gas. Bell considers that the economy resulting by the use of Ferrie's furnace is due to its height alone, but it is fair to state that Ferrie's explanation is held by many ironmasters of eminence.

Hot Blast.—The first idea of heating the blast, prior to its entrance through the tuyeres into the furnace, is due to J. B. Neilson, of Glasgow; who also has the merit of its first practical application early in the year 1829. Previous to that period, observes Henry Martin, in an interesting paper read before the Inst. of Mechanical Engineers, the settled and firm conviction of ironmasters appears to have been that the colder the blast the better the quality and the larger the quantity of iron produced from each furnace in a given time. This conviction was the result of long-continued observations, which showed that the produce of each furnace was always more in winter than in summer; and as the difference most appreciable to the furnace managers between the one state of circumstances and the other was the temperature of the atmosphere, this without further investigation was at once charged as the sole cause. Subsequent research, however, has shown that the mere variation of temperature in the atmosphere from freezing-point to summer-heat had nothing to do with this result, which is owing to a cause still as actively in operation and as sensibly felt with the blast heated to a temperature of 600° or 800° Fahr., namely, the excess of moisture, in the shape of invisible vapour, contained in the air in the warm weather as

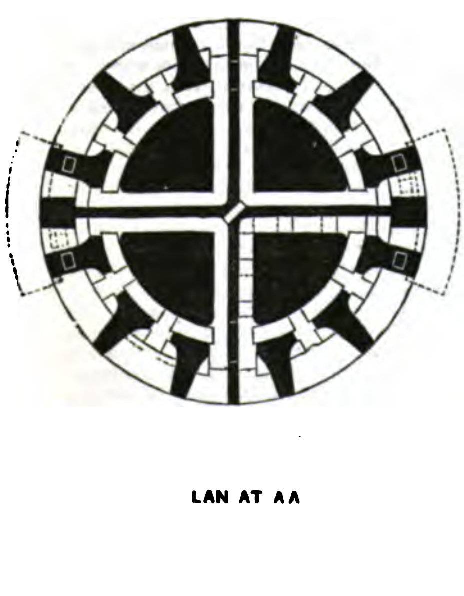
4249.



4250

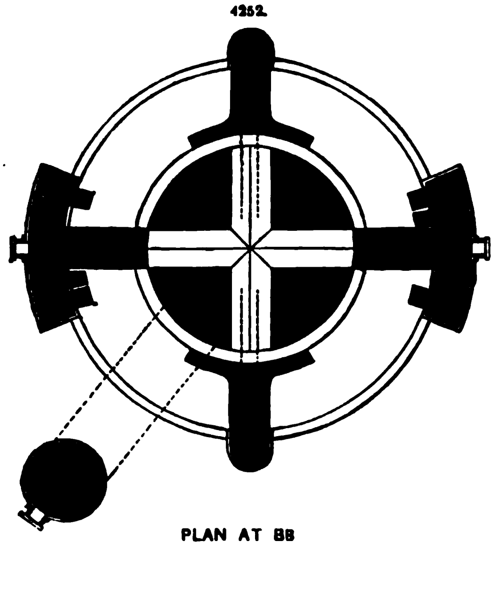


4251.



LAN AT A A

4252.

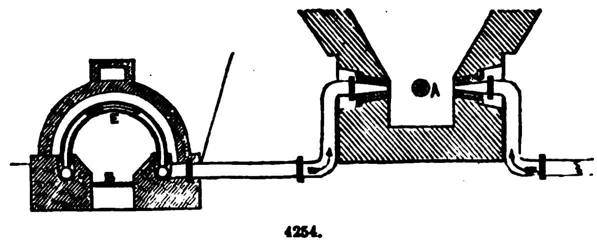


PLAN AT BB

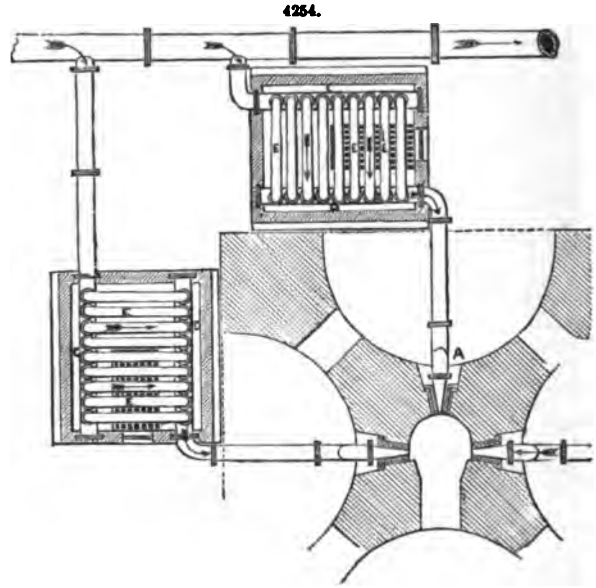
compared with the cold. So strongly rooted, however, was the belief that the temperature was the only circumstance affecting the make of iron, that the greatest efforts were made in summer to obtain the blast as cool as possible; amongst other plans, by passing it over cold water, with a result of course contrary to expectation, owing to a partial absorption of the water.

After many experiments with the original apparatus, which, whilst proving the correctness of his ideas, was found mechanically to be very defective, Neilson introduced in 1832, at the Clyde Iron-works, the cast-iron tubular stove, Figs. 4253, 4254. An oven or stove with one grate was constructed behind each of the tuyeres, tuyere A being inserted at the back of the furnace, in addition to the two, one on each side, which were used before the introduction of hot blast. The blast was admitted into a main pipe C running longitudinally at one side of the grate B: on the top of this main pipe a number of deep circular sockets were cast with apertures into the pipe, and on the opposite side of the grate a similar main pipe D was fixed with corresponding sockets and apertures, which was connected with the tuyere-pipe inserted into the furnace. The two longitudinal main pipes C and D on each side of the grate were then connected by cast-iron tubes E, each forming a semicircular arch of 6 ft. span, fastened into the sockets with well-rammed iron cement. The cold blast was supplied to each of the ovens by a branch pipe taken direct off the large main from the blast-engine, and entered the oven at the end farthest from the grate; it then passed through the arched tubes E over the fire into the pipe D on the other side of the grate, and thence to the tuyere, leaving the oven at the end next the grate. Whilst the blast was traversing the two longitudinal pipes and the arched connecting tubes, it received the direct heat from the grate, and was raised by this means to a temperature of 600° Fahr. The whole of the apparatus was enclosed in an arched oven, so as to retain and reverberate as much heat as possible. The general dimensions of the apparatus for each tuyere were;—Diameter of longitudinal mains at each side of grate, 12 in., length of ditto, 10 ft., distance between ditto, centre to centre, 6 ft.; number of arched connecting tubes, 9; internal diameter of ditto, 4 in.; external diameter of ditto, 7 in.; height from grate to under side of arched tubes, 4 ft. 4 in.; area of heating surface a tuyere, 150 sq. ft.; area of fire-grate a tuyere, 15 sq. ft.

4253.



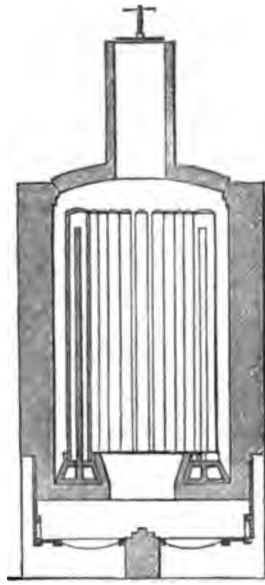
4254.



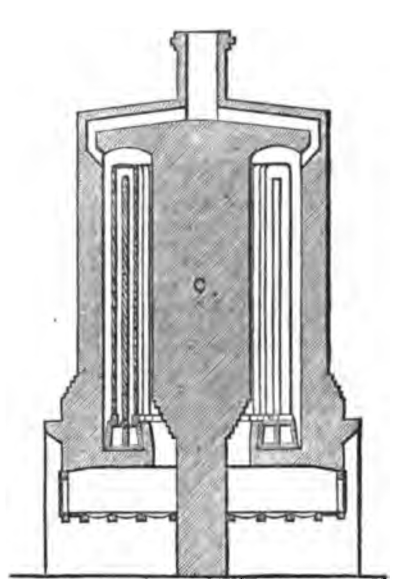
Figs. 4255, 4256, are of Martin Baldwin's hot-blast ovens. From 1832 to 1851 numerous modifications of Neilson's plans were used with varying success, but they all had defects which prevented their final adoption. Bearing in mind these defects, Martin Baldwin in 1851 directed his efforts—1st, to the construction of a main of such a form that its expansion or contraction should in no way tend to disturb the socket-joints of the upright pipes; 2nd, to the construction of upright pipes that should have all the expansion they required without tending to disturb the socket-joints or to break or burn down; 3rd, to the construction of a form of casing which, whilst it gave a good fire-grate area, should be compact and as far as possible reverberatory, so as to throw back the heat on to the pipes and present as little surface as possible for its abstraction from the oven. It will be seen from the plan, Fig. 4256, that the form of main designed was well adapted for the purposes in view; being circular or annular in plan, cast in two semicircular portions, with a longitudinal diaphragm through the centre dividing each portion into two compartments: on the upper side of each semicircular portion twenty-four socket-holes were cast, twelve in each compartment, making forty-eight total. In the middle of the outer compartment of each main, between the sixth and seventh socket-holes, a stop S was cast; and at either end of the main an inlet and outlet branch was cast on, communicating with the outer compartment. The two mains being placed on a brick foundation with fire-grates below formed a complete circular main, ready for the insertion of the upright pipes. These consisted each of two straight pipes about 11 ft. long, cast together, with spigot ends at the bottom fitting into the sockets on the main, and closed at the top with the exception of a lateral opening to permit one side of the pipe to communicate with the other. Each pipe was

4 in. inside diameter and 1½ in. thick. Twenty-four of these pipes were fixed in the sockets on the mains, the joints well rammed with iron cement; and a circular casing of masonry lined with fire-brick was erected round them, and surmounted with an arched dome and stack. The cold blast, entering at the same end of each main through the inlet-pipes placed side by side, traversed first the outside compartment of the mains as far as the stop S; and then passing up the outer portion of the first six pipes and down the side next the fire, it arrived at the inner compartment of the mains, from which it passed up the inner sides of the next six pipes and down their outer sides into the outer compartment of the mains beyond the stop, and thence issued through the outlet branches at the hot ends of the mains.

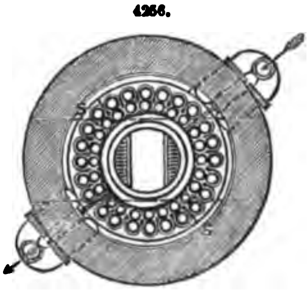
4255.



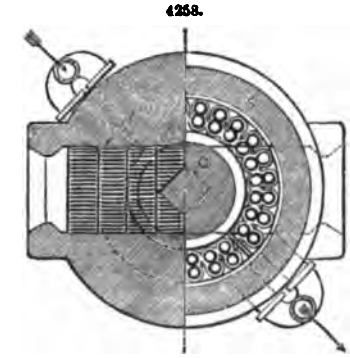
4257.



4256.



4258.



This oven was found to give a satisfactory heat, though not superior to that obtained with some of the other descriptions of ovens; but in freedom from fracture or leakage of joints it was soon found to be very greatly superior to many others.

In consequence of its freedom from fracture or leakage, attempts were early made to improve the mode of setting of this round oven, so as to obtain a larger heating power from it. One of the first defects observed was the position of the stack-flue directly over the fire-grate, by which arrangement a large amount of the column of heated flame and gases, instead of being distributed amongst and about the pipes, passed direct out at the stack without coming in contact with them. To obviate this difficulty, in the next oven erected the hole through the brick dome at the top communicating with the stack was built up, and the flues distributed round the outside casing of the oven at the top, so as to create a draught from the grate to the back of the pipes all round. This was found to be a considerable improvement, but was to some extent counteracted by the casing of the oven being set back 14 or 15 in. from the pipes, in order to allow of back flues being taken under the mains from the grate, that some heat might ascend at the back as well as the front of the pipes; by this means a considerable amount of the reverberatory effect of the casing on the pipes was lost. It will be seen also that in the first form of round oven, Figs. 4253, 4254, a fire-door was placed at both the cold and hot ends of the grate: this was found to be very detrimental, especially in a high wind, as the comparatively free draught playing under the grate frequently blew the fire out at one door when blowing full in at the other, interfering seriously with the proper draught up the oven. These various defects were remedied by a different mode of setting: the second fire-door was done away with, and the ash-hole blocked up at that side; the brickwork was retained, as at first, close to the pipes, with only about 4 in. space; and the top flues were placed round the outside of the casing, so as to distribute the heat as much as possible among the pipes, with considerable advantage in the increased heating power of the oven.

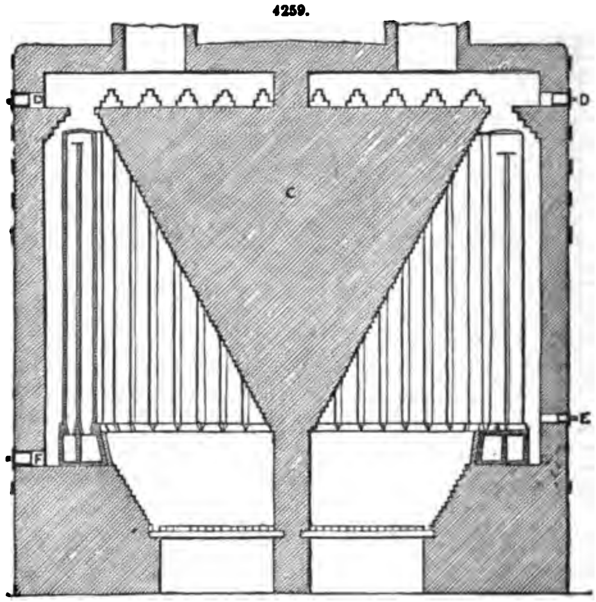
Figs. 4257, 4258, show a further improvement of the round oven, representing one constructed in 1857, with an internal core C, at Henry Martin's suggestion, for Halloway's iron-works in the Forest of Dean. This arrangement has been found to be a valuable improvement, increasing the heating capacity of the round oven to the extent of one-third with a smaller consumption of fuel. The advantages of a core consist in affording a greater amount of reverberatory surface; in

making the temperature more uniform by absorbing any excess of heat, and giving it out again on any diminution of temperature; and in occupying the large vacant space in the centre of the oven, thereby compelling a much larger amount of the heated gases to come into contact with the pipes. The area of fire-grate in this oven is 38 sq. ft., and the area of direct heating surface in the pipes 850 sq. ft. or 280 sq. ft. a tuyere for three tuyeres; it is capable of heating the blast for three tuyeres to a temperature of about 800° Fahr.

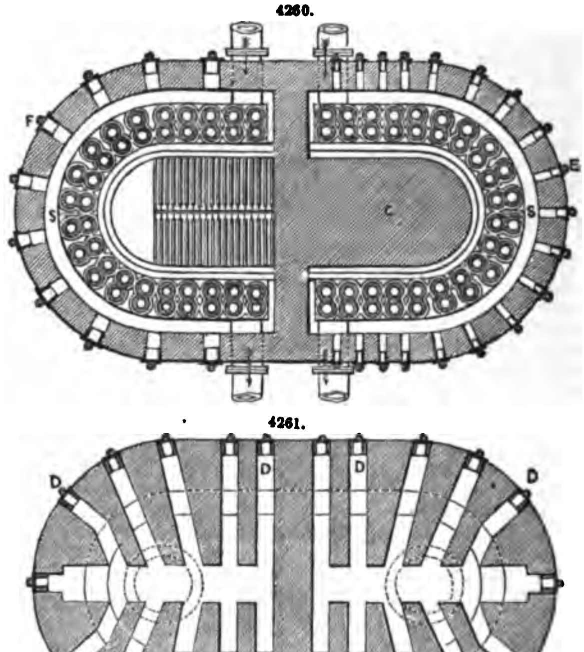
Shortly before this last form of round oven was erected, Josiah Smith, of Dudley, who had paid great attention to the subject, and to whom in a great measure the previous improvements in the setting of the round oven were due, finding that he required rather more heat than one round oven would afford, and not wishing to go to the expense of erecting two, devised the plan of elongating the semicircular mains of the round ovens by the addition of a straight length of pipe at the extremities of each, thus forming an oval main and increasing the number of pipes from twenty-four to thirty-two in each oven, and at the same time affording a considerable additional space for the fire-grate. This was found to be so great an improvement on the ordinary round oven, that in the next one constructed the mains were further elongated so as to hold eighteen pipes each, or thirty-six an oven, with a proportionate increase of fire-grate; at the same time a middle partition wall was built between the two mains, the oven was thus divided into two distinct compartments, so that one half could be cleaned out at any time without interfering with the other.

In the next example of oval oven the middle wall was overhung on each side by course over course being gathered over, thus forming a core, which was found to produce the same striking improvement as in the round oven before described. An oven on this construction, with 56 sq. ft. of grate area and 1350 sq. ft. of direct heating surface, was in 1859 heating the blast supplying seven tuyeres to a temperature of 800° Fahr. at Martin's works at the Parkfield Furnaces. Figs. 4259 to 4261 show a further example of this mode of construction in the case of an oval oven with core having forty pipes, erected by Martin in 1858 at Parkfield, in which the area of fire-grate is 54 sq. ft. and the area of direct heating surface in the pipes 1500 sq. ft., or 250 sq. ft. a tuyere for six tuyeres.

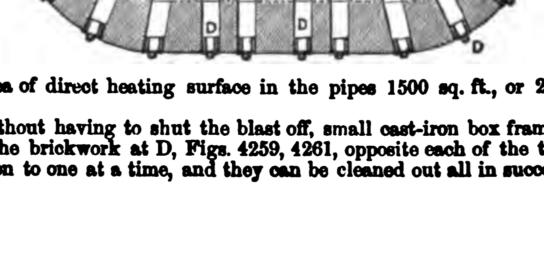
4259.



4260.



4261.



In order to cleanse the oven without having to shut the blast off, small cast-iron box frames with doors have been inserted in the brickwork at D, Figs. 4259, 4261, opposite each of the top flues; by which means access is given to one at a time, and they can be cleaned out all in succes-

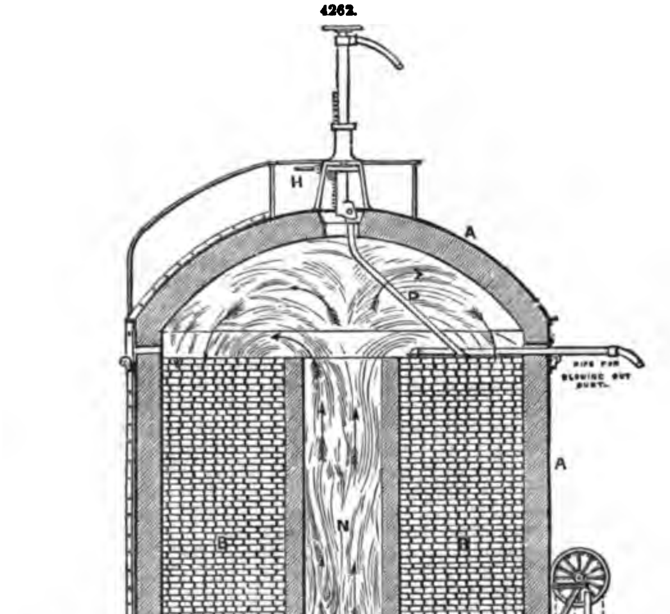
sion in a few hours without interfering in any way with the working of the oven. The dust removed in cleaning these flues would to some extent fall down in between the upright pipes and behind the main pipe. To cleanse these parts of the oven, small box frames are inserted at E, Figs. 4259, 4260, opposite each space between the pipes and near the socket-joints, so that all rubbish or dirt which might accumulate between the pipes can be removed; and similar cleansing holes placed behind the main at F enable the process of cleaning to be completed. Though this might be considered a minor point, it is really one of considerable importance in an oven such as that described; for in consequence of the freedom from liability to fracture or leakage, the oven can thus be kept continuously at work for many years without the necessity for the blast being once taken off for cleaning out the oven.

We extract the following particulars relating to improvements in regenerative hot-blast stoves for blast furnaces from a paper read before the Inst. C. E. by Edward Alfred Cowper, in May, 1870;—

In the year 1828 Neilson introduced the plan of heating the air employed as blast in the way we have described, p. 2056; and subsequent improvements have enabled us to obtain with pipe stoves a temperature of 900° and in some few cases 1000° Fahr. The wear and tear, however, with such temperatures of blast are considerable, and great care is requisite in the management of the stoves, or they would soon melt or be destroyed, whenever the current of cold air through the pipes is stopped, as, for instance, at the time of tapping the furnace.

It will be readily understood that, when cast-iron pipes are used for heating the blast, they must be considerably hotter than the air passing through them, or the conduction of heat would be very slow. Then, again, the heat of the fire, or of the products of combustion, must be considerably higher than the pipes, in order that they may be heated with sufficient rapidity to produce the necessary result. There are thus two losses by conduction, besides that through the metal itself, and the natural result is, that the products of combustion generally pass away from the stoves at about 1250°, causing one great loss of heat, besides failing to heat the blast to the desired degree.

4262.



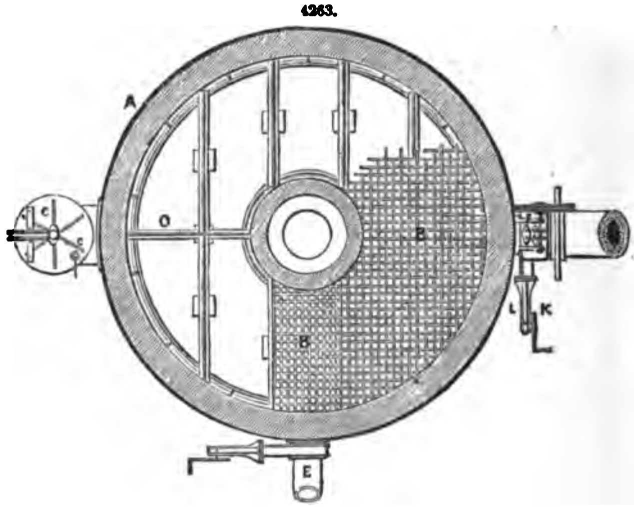
The friction of the air through the pipe stoves, or the reduction in the pressure of the blast, or pillar of blast, as it is commonly termed, is always considerable, and the leakage of air or loss of blast is likewise an item with pipe stoves; and when they get out of repair, from the warping and twisting of the pipes, and consequent straining of the numerous joints, the leakage becomes so considerable that the stoves have to be laid off for some time for heavy repairs. This is such a serious matter that pipe stoves are often worked in a leaky condition, necessitating the expenditure of engine-power for blowing air uselessly, in place of its being utilized in the blast furnace.

The stoves, Figs. 4262, 4263, are based upon the principle of the regenerative furnace introduced by Siemens. Each stove of a pair consists of a wrought-iron cylindrical casing of light boilerwork A A, having a flat bottom standing on the ground and a dome at the top. It is lined with brickwork throughout, and is provided with a circular central

shaft or flue N, which extends to within a few feet of the inside of the brick dome. Around this shaft there are a number of compartments or boxes B B, formed of bricks so placed that those in one course are not exactly coincident in position with those in the courses either above or below, though a passage is left open from the top to the bottom of the mass of brickwork. Thus a new kind of regenerator has been introduced, which is supported on cast-iron gratings at the bottom or cool part of the stove.

The wrought-iron casing A A, Figs. 4262, 4263, is provided with several valves, three being for the admission of cold blast E, of gas K, and of air for combustion L, and two being for the exit of the products of combustion O and of the hot blast F. These valves are all of simple construction except the hot-blast valve F, which has a small circulation of water through it to keep it sufficiently cool, just as the temperature in a tuyere is kept down by a circulation of water around it. This has always answered the purpose very well. The opening and shutting of the valves at intervals of several hours are matters of simple routine, and are in fact all the attention the stoves require beyond an occasional observation to see that the stove has gas enough. There is no fear that these stoves will get too hot, as it is fire-brick that is being heated and not cast-iron pipes. Supposing, then, that a stove has been regularly at work heating blast, and it is wished to heat the stove up again, the first thing to be done is to put another stove on, and then shut the hot and the cold blast valves F and E, and allow the air in the stove to blow out at a small valve *c* to reduce it to atmospheric pressure. The gas, air, and chimney-valves K, L, and O, are then opened, and the gas at once ignites as it enters, and gives a large volume of flame right up the central shaft and over and into the regenerator, thus heating the top course of brickwork considerably, the next course rather less, the next still less, and the lower part of the regenerator not at all, the products of combustion passing away to the chimney at a temperature of about 300°. Then, as the heating goes on, and large quantities of heat are taken up by each course of brickwork, the heat penetrates by degrees lower and lower into the regenerator, until a good red heat has, in the course of several hours, reached nearly to the bottom, thus storing up a large amount of heat in the bricks forming the regenerator. The gas and the air are next shut off; the chimney-valve is also shut, the cold blast is put on, and lastly, the hot-blast valve F is opened. The stove then again does duty in heating blast to full red heat; that is, at a temperature of 1400° to 1500°.

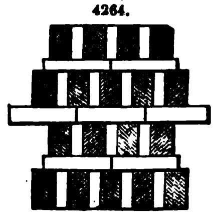
4263.



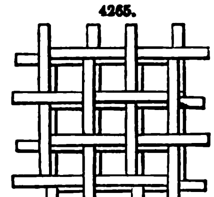
All the hot-blast pipes from the stove to the furnace are of wrought iron and of large size, so as to allow of several rings of brickwork lining to prevent loss of heat.

When Cochrane and Co. adopted the regenerative hot-blast stoves some years ago at their works at Ormesby, it was at first contemplated to use the waste gas from the top of the blast furnace for heating the stoves. On consideration, however, it was thought that the dust mixed with the gas might choke up the regenerators, as they were at that time always filled with chequered work; the bricks being so placed, Fig. 4264, that in every case a brick stood over a narrow slit or passage, though a little above it, thus stopping and splitting the current of air, and effectually

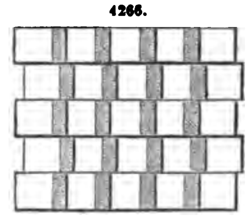
4264.



4265.



4266.



preventing any brush from being passed through the slit. The new arrangement is shown in plan, Fig. 4265, and in section, Fig. 4266. Again, a blast of air or steam through the slit was ineffective for blowing out dust, because there existed free horizontal openings in all directions, by which the force of a blast applied to a slit was at once dispersed and lost.

Cochrane therefore erected Siemens' gas producers, and for some years worked the stoves most successfully with gas so produced, and which contained no dust. After this, they built large brick chambers, with an extensive series of shelves inside, for the purpose of catching the dust entering with the gas from the top of the blast furnace, which was passed through such dust-catchers before

being used in the hot-blast stoves. Now, however, by the use of the later improvements, invented by Siemens, Cochrane, and E. A. Cowper, and embodied in the stoves just described, the cost of such dust-catchers is avoided, and the expense of producing gas is also saved, as the gas is used direct from the top of the blast furnace, and the stoves can be cleaned out with the greatest facility.

The arrangement of blast-pipes, for air or steam under pressure, for cleaning out the dust from each compartment or set of boxes *seriatim*, is shown at P and at Q, Fig. 4262. That at P consists of a wrought-iron pipe jointed to a central pipe capable of revolving by a worm and worm-wheel, so as to bring the pipe over each box in succession, and blow violently down it to clear out all dust. The central pipe has a slight vertical motion given to it each time the pipe P is brought nearer to the centre of the stove. The blast-pipe Q, shown in dotted lines at the bottom part O of the stove, has a small sheet-iron cone or umbrella attached to it, to keep the dust off the workman when he applies the pipe to blow upwards through the boxes. The bottom part of the stove where the cold blast enters is always very cool, and can at any time be made quite cold by running the cold blast through for some time longer than usual, and then a man can enter at the chimney-valve at any time. The construction of the regenerator in compartments or boxes, connected together vertically but not horizontally, gives the power of applying the blast with efficiency, inasmuch as the whole force of the blast is confined to the one passage that is being blown at the time, and admits of a good brush, like a chimney-sweeper's brush, being passed up or down through the boxes to brush out the dust if preferred, the brush being provided with a long-jointed or flexible handle.

The form and proportion of the passages have been found, after numerous experiments, to produce an excellent effect in stirring up and mixing the air passing through, inasmuch as the current is caught by the two contiguous sides of the box that overhang the one below it, and thus is, so to speak, turned over and over, first on one side and then on the other, producing a most intimate mixing of the air, and therefore quick and good conduction of heat from the hot bricks to the air, or *vice versâ*, from the products of combustion to the bricks. It is obvious that the same surfaces that take up the heat are those that again give it out to the blast, so that there is but little loss from bad conduction; and the cold blast is thus heated to a high temperature, and the products of combustion are cooled to a low temperature, in fact nearly exchanging their temperatures, instead of the products of combustion, as in the old cast-iron pipe stoves, going away far hotter than the temperature of the blast that then obtained.

As a rule, a small stick of lead was employed as a test, to ascertain if the blast was hot enough in the pipe stoves, as it would melt the lead if hot enough; then zinc was used in like manner; but with the regenerative stoves antimony is required, and that is cut or melted in three or four seconds. Glass rods are melted easily.

The results obtained by Cochrane and Co. from the adoption of these stoves, as regards the quality of the iron, the increased make of iron, and the large saving of coke in the blast furnace, have been most satisfactory. Hitherto there has only been one drawback to the use of gas direct from the top of the blast furnace, namely, the dust, which has prevented the extensive employment of the regenerative stoves. As that difficulty has now been overcome, many ironmasters are contemplating their immediate use, and several are erected at Barrow-in-Furness of a larger size than any made previously, besides others of a smaller size in other parts of England, in France, and in Germany.

A form of hot-blast stove, Figs. 4267 to 4269, has been introduced and worked successfully at the Consett Iron-works by Thomas Whitwell. It presents in common with Cowper's stoves the advantage of using fire-brick instead of iron in its construction; it is exceedingly durable, stands a temperature of upwards of 1800° without damage, is readily cleaned, and in certain cases effects a considerable saving in fuel to the ton of iron made.

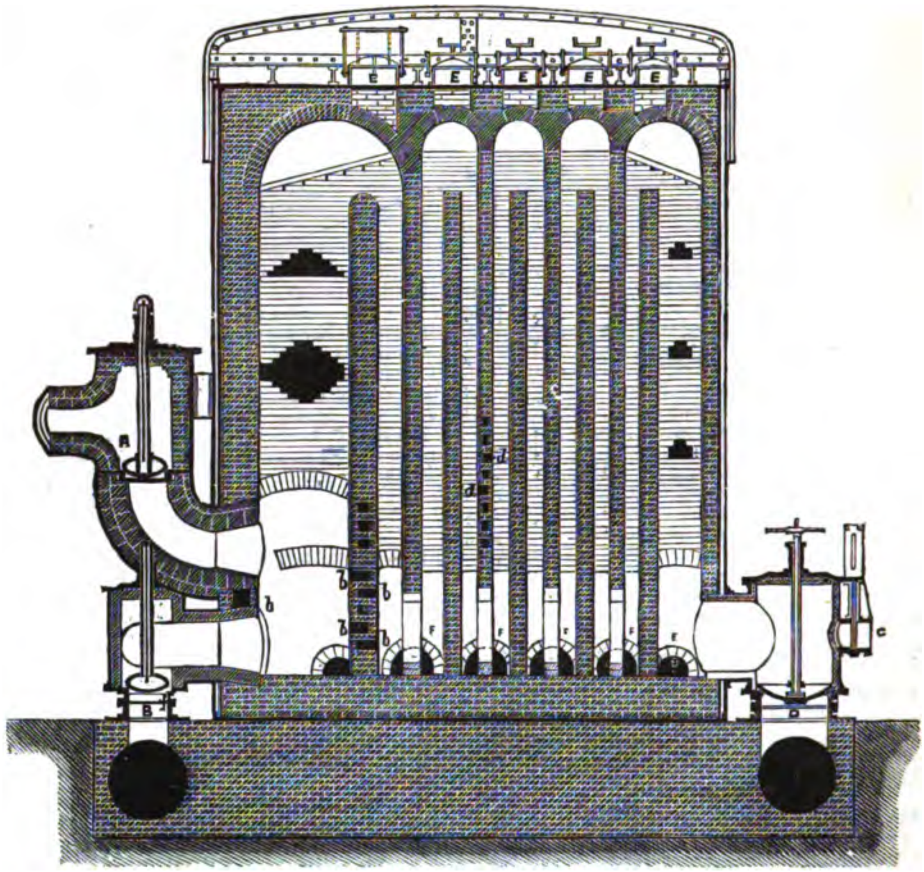
Fig. 4267 is a vertical section of Whitwell's stove. The hot-blast valve A and the cold-blast valve C being closed, the gas-valve B is opened, through which the gas enters the stove, traverses up and down the spaces between the upright walls, and enters the chimney-flue by the valve D. Heated air is supplied to the gas by means of the air-valves *a* and *c* and passages *b* and *d*, by which an intense combustion is secured. The chimney-valve D and gas-valve B being closed, and the hot-blast valve A being opened, the cold blast is admitted through the cold-blast valve C, and issues from the stove by the valve A *red hot;* all other valves being closed perfectly tight. When it is required to clean a stove, the top cleaning doors E are opened, and the walls scraped with the cleaning tools, when the dust deposited on the heating surfaces falls to the bottom of the stove, and is removed by the bottom cleaning doors F.

With respect to the mooted question of the correct temperature of the blast, it is fairly summed up in some remarks made by Sir William Fairbairn before the Inst. of Civil Engineers;—"Fairbairn stated that the quality of iron had been greatly improved since the introduction of the hot blast. This arose, in his opinion, from the higher temperature of the blast, which not only tended to increase the temperature of the furnace, but raised the melting-point of the ore, and volatilized the phosphorus, sulphur, and other injurious elements, which, at a lower temperature, combined with the iron. This was certainly not the case since the blast had been raised from 600° to 900° or 1000°; and he believed that if the temperature was increased from 1000° to 1500°, the quality would be still further improved, and the value of the produce greatly enhanced. In his early investigations of the comparative value of hot and cold blast iron, he did not discover much difference in their mechanical properties; but many of the ironmasters took advantage of the discovery to remelt their old cinder heaps, and the result was a description of iron little better than pipe-clay, which gave the hot blast a bad name, and caused engineers, without further inquiry, to insist on having cold blast in their cast-iron constructions. At the present time little or nothing was said of the difference between hot and cold blast iron."

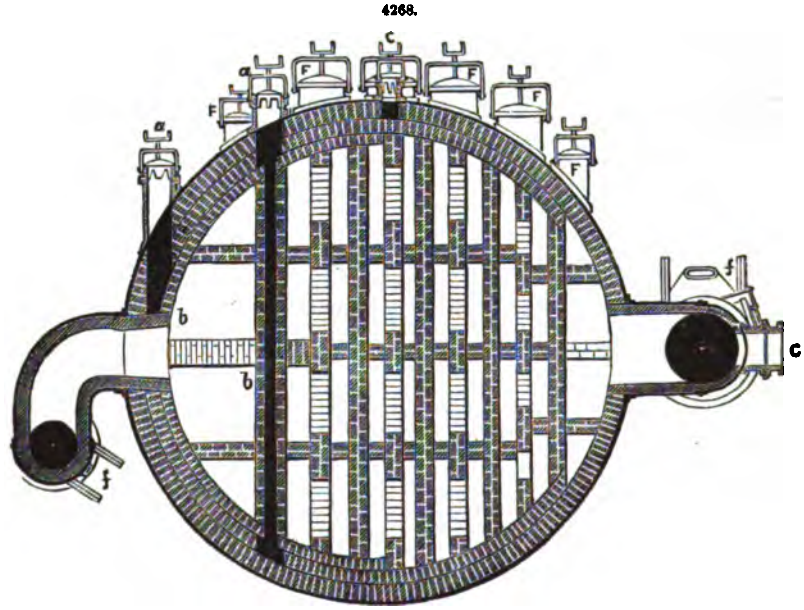
Cupola Furnaces.—In cupola furnaces the blast enters generally either through tuyeres or through horizontal or vertical slits at the sides of the cupola; but a disadvantage attends these arrangements, inasmuch as the blast being too cold at the beginning to combine at once with the carbon

of the fuel, must first be diffused through the fuel before it can burn, and the greatest heat is therefore produced at a point situated above the tuyeres. The height of this point varies with the

4267.

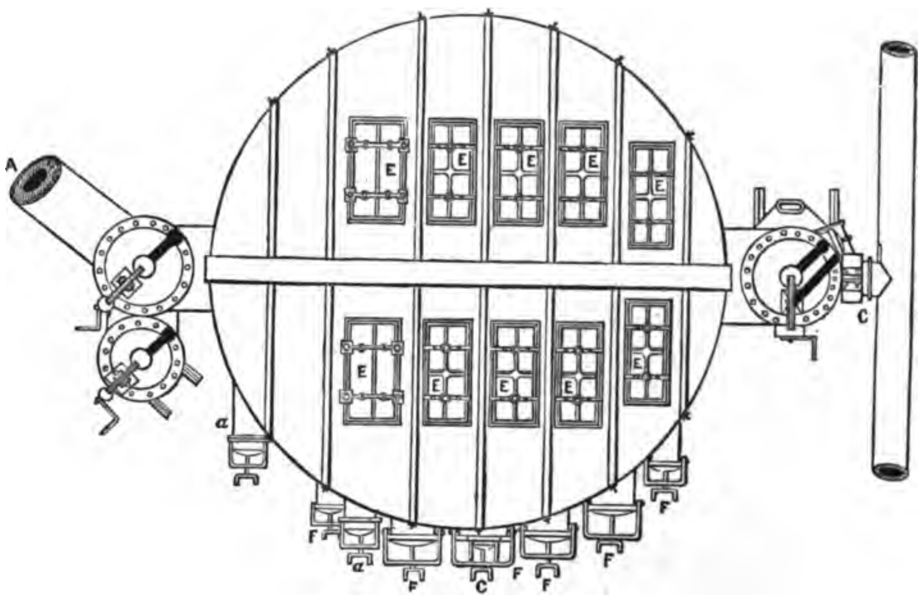


4268.



respective quantities of fuel and of blast that are introduced; and when sufficient fuel is supplied, the point of greatest heat will be situated at the level, where all the oxygen in the blast has

4269.



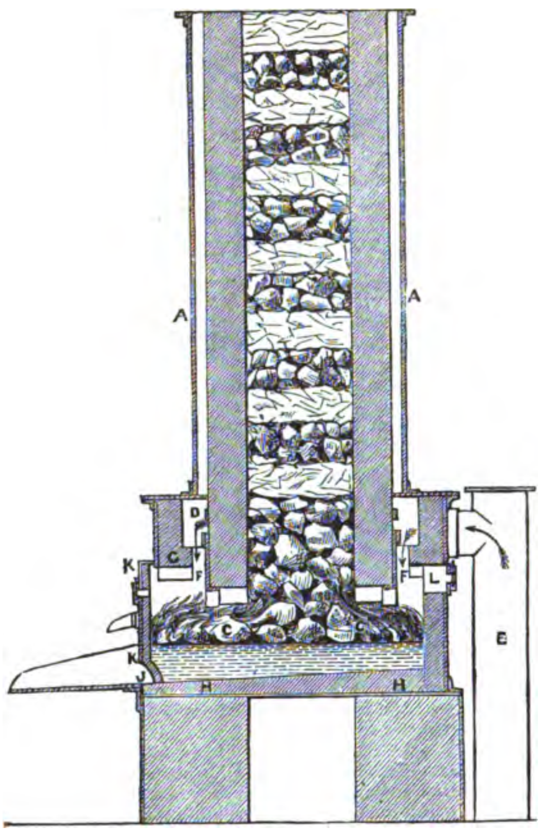
become carbonic oxide. It is found in practice that the range of level of this point extends over several feet, according to the quantity of fuel used, the height being generally about 3 ft. above the level of the tuyeres; but in the cases mostly met with in foundries there is not a sufficient supply of fuel close to the tuyeres or openings where the blast enters, and in these cases, therefore, the blast does not meet with sufficient fuel for complete combustion until it arrives at the upper layers of the fuel, and it consequently passes the hot metal and causes it to be burnt. The waste upon the metal put into the cupola amounts to from 5 to 10 per cent. generally in these furnaces; and the rapid burning away and destruction of the lining extends over a height of 5 to 6 ft. from the hearth. Another disadvantage, resulting from the necessarily confined space occupied by the tuyeres or blast openings, is that the blast, being thereby concentrated, acts upon the carbon contained in the iron, and consequently deprives the iron more or less of its fusibility.

To remove these disadvantages of the ordinary construction of cupolas, says Jacob Eichhorn, in a paper read before the Institution of Mechanical Engineers, a plan has been devised and carried out successfully by Henry Krigar, of Hanover. Krigar's plan aims at the accomplishment of the following objects;—To concentrate the heat in the lower part of the cupola, where there are facilities for easily repairing the furnace lining, and to render the action of the cupola uniform throughout the operation of melting; to give the hearth such a size that the column of fuel between the layer of melted metal and the level where the blast enters the interior of the furnace may vary but little in height, so as to limit the range of the destructive action upon the furnace lining; and to ensure the blast being taken up by the carbon of the fuel from the moment of its entering the furnace, and so prevent it from injuring the heated metal by oxidizing it.

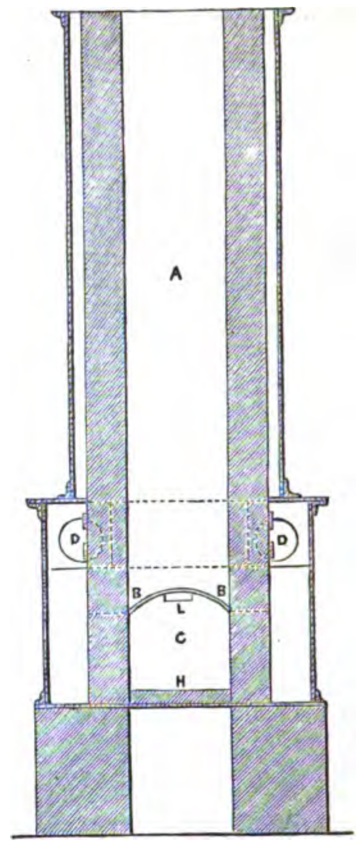
The construction of Krigar's cupola is shown in Figs. 4270 to 4273. Fig. 4270 is a vertical section from front to back; Fig. 4271 a vertical section from side to side; and Figs. 4272, 4273, sectional plans at different levels.

The vertical shafts A A of the cupola are made rectangular in form, either square or oblong, as shown in the plan, Fig. 4272, and parallel or with very little taper in height, so as to avoid any prominent part upon which the flame could strike, and which would be exposed to rapid destruction. A backing of sand is used behind the brickwork to concentrate the heat in the cupola. The shaft A is supported at front and back by arches B B over the lower chamber C C; and at the sides of this chamber is also a backing of sand to keep the heat in. Over this backing and round the bottom of the shaft A runs the air-passage D D, into which the blast is delivered from the two air-mains E E; and the blast entering through this passage cools the brickwork of the cupola, and becomes heated itself; it then passes down into the melting chamber C C through the two long slots F F in the roof, one at the front and the other at the back, Figs. 4270, 4272, extending the whole breadth of the hearth. These slots are constructed by leaving a space of 4½ in. width between the outer arches G, Fig. 4271, and the inner arches B B that carry the shaft A; the length of the hearth H from front to back is consequently made greater than the breadth. The front of the cupola is closed by an iron door K on hinges, extending the whole breadth of the hearth; and a smaller door L is placed at the back, to facilitate the drawing of the cupola by inserting a rake at the back; by this means the drawing of the cupola can be accomplished regularly within three or four minutes.

4270.



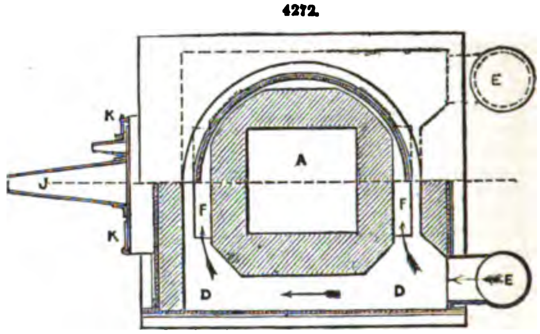
4271.



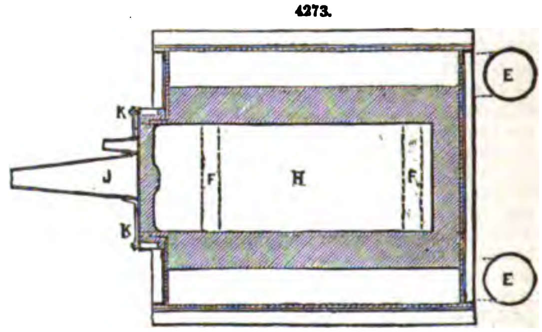
For starting the cupola, about 1 to 1½ cwt. of coke is placed on shavings or some burning coke upon the hearth, and more is added by degrees from the front door, until all the coke intended for the first filling is put in. The door K is then closed, being first wetted on the inside; and the tapping hole J is formed as usual by placing clay round a wetted stick. The whole height of the door is then plastered on the inside with a mixture of clay and sand, the door being set forwards about 5 in. in front of the breast of the furnace, to allow space enough at top for the furnace-man to get his arm in for lining the door; and the space at top is afterwards closed with bricks. This mode of closing is adapted for cupolas working with a pressure of blast of from 4 to 7 in. of water; but where the blast is stronger, a wall of coke is first built up inside the melting chamber C and wetted; and the door being shut and secured with wedges, the space between the door and the wall of coke is then filled with foundry sand rammed in.

The amount of filling that is put in for starting the cupola varies with the size of the cupola and the quantity of melted metal that the hearth is intended to contain at once; but the amount is always much less than is

4272.



4273.



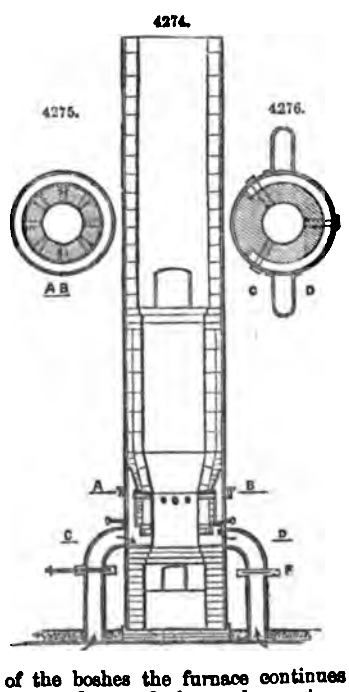
usually employed in other cupolas. One of the Krigar's cupolas, capable of melting 3 tons of iron an hour, requires a filling of 2¾ cwt. of coke for starting it, or 3¾ cwt. when it is intended to keep the whole of the melted metal in the hearth, to be tapped all at once. Upon this filling a charge of 8 cwt. is added from the top of the cupola shaft, and then about ½ cwt. of coke; and the same in succession, until the whole charge is put in, filling up the shaft A to the top, as in Fig. 4270. After the casting, a certain quantity of the coke is drawn out unconsumed. The average quantity of coke consumed is 1½ cwt., or 168 lbs. the ton of iron melted, when only 3 tons are melted in each charge; and the consumption is 147 lbs. the ton when charges of 6 tons are melted; and 140 lbs, the ton with heavier charges.

The metal melted in this cupola is found to be very fluid, and indeed so fluid, that in the cases where in an ordinary cupola seldom more than one-half of cast-iron scrap is used, this cupola bears under the same circumstances the addition of fully three-quarters of scrap. At the same time the softness of the metal is retained; or, as it is commonly termed, the metal is clean. If the cupola be allowed to stand without blast for an hour after the filling is completed, and the blast be then turned on, the metal begins to run down to the tapping hole six minutes afterwards; but if the blast be admitted immediately on completion of the filling, without allowing the cupola to stand, the metal may be made to run from the tapping hole within one hour from the time that the cupola was empty before filling commenced.

This cupola has the advantage of allowing the whole of the metal melted during one hour to be retained in the hearth; the result, however, is not obtained by increasing the height from the bottom of the hearth to the crown of the arches carrying the shaft, but by increasing the length of the hearth from front to back, as shown in Fig. 4270. If the height from the bottom of the hearth to the arches is made too great, the metal loses the great fluidity that distinguishes the working of this cupola. The height from the tapping hole J to the charging opening at the top of the shaft A is from 13 to 14 ft. As the construction of the cupola causes it to work hotter than ordinary cupolas, it requires a smaller area of shaft than an ordinary cupola for the same blast and yield, the reduction being in the proportion of about 3 to 7; any existing cupola shaft can therefore be altered to this plan, and will still yield more metal than before in the same time.

The quantity of blast required is 30 cub. ft. a second, reduced to the pressure of the atmosphere, for each ton of iron melted an hour. The pressure of the blast used may be as low as 4 to 5 in., but a pressure of 8 or 9 in. is generally adopted. Whether this or a still higher pressure is used, no further economy of fuel is obtained, but only a greater quantity of metal is melted down in the same time by the same furnace.

With regard to the wear and tear of the cupola, the lower part of the shaft A is exposed to the greatest destruction, but that is the only portion which suffers more than the lining of an ordinary cupola, and it is easily accessible for repair. The coke falling from the shaft into the melting chamber C C, Fig. 4270, stands there in a heap, upon which the blast rushes through the two transverse slots F F in the roof; and the heat from the burning fuel being radiated into the air-passages D D, the blast becomes prepared for combining rapidly with the carbon of the fuel, before it has an opportunity of coming in contact with the melting metal and wasting it by oxidation; and the action of the blast is finished, as may be judged from the appearance of these cupolas, at a level of only about 14 in. above the crown of the arches B B. This corresponds to the portion of the cupola that requires to be renewed about every three or four months, and a small arched iron bar of 2 or 3 in. width, remaining constantly in its place in each arch B, allows of the arches being readily replaced at any time without the introduction of centring. The shaft A suffers very little wear itself, and after six months' work it can only be said that the bricks are strongly glazed. When the arches B B are replaced every three or four months, the face only requires patching or plastering up once or, at the most, twice a week; and only about half or little more of the repairing material is required that would be necessary in an ordinary cupola. The total cost of wear and tear therefore does not at most exceed that of the ordinary cupolas, while there is less trouble in keeping Krigar's cupola in repair.



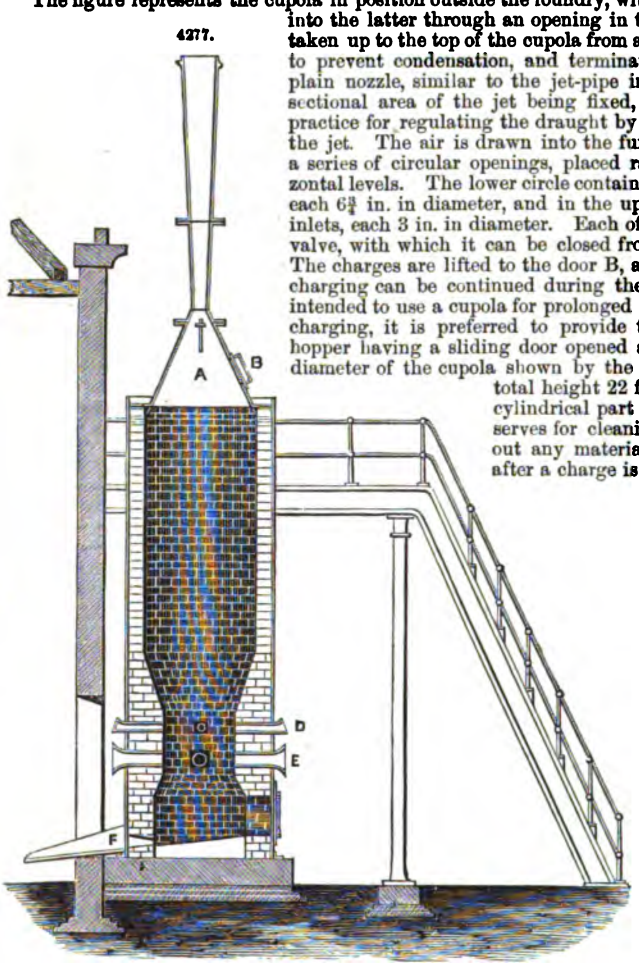
With regard to economy of metal, the results of the working of this cupola are found to be that in melting pig iron, such as Calder No. 1, the loss amounts to 3·4 per cent. on the metal weighed in; and when mixed with three-fourths of railway-chair scrap, the loss is only 2·2 per cent.

Figs. 4274 to 4276 are sections of one of Ireland's cupolas, of which a large number are at work in England. The cupola has two rows of tuyeres, and is made with boshes like a blast furnace. In the lower row there are three tuyeres, each 6 in. in diameter inside, whilst in the upper row are eight tuyeres, having a diameter of 2 in. at the nozzles. The centres of the two rows of tuyeres are 1 ft. 7 in. apart vertically. The lower part of the furnace is 2 ft. 6 in. in diameter, its size being reduced where the tuyeres are inserted to 1 ft. 8 in. The boshes are 1 ft. 9 in. high, and enlarge from 1 ft. 8 in. to 2 ft. 9 in. in diameter. From the top of the boshes the furnace continues 2 ft. 9 in. in diameter for a height of 4 ft. 9 in. to the charging door, and then enlarges to a

diameter of 3 ft. 3 in. for the remainder of its height. The total height of the furnace from the floor to the top is 21 ft., and the diameter outside the iron casing 4 ft. 1 in. In charging this furnace it should be filled with coke to the top of the boshes, and four separate hundredweights of iron, alternated with 3 cwt. of coke, then be introduced to fill it up to the charging door. In these furnaces a ton of freely-running iron has been run down by 1¾ cwt. of coke, but more usually from 2 to 2½ cwt. are required. Great care should be taken that the furnace is kept to its proper shape by daily, or at all events frequent, repairs. The charges should also be made level, and not thicker in one place than another.

Fig. 4277 shows some of the principal details of a cupola furnace blown by steam-jets, as constructed by Woodward Brothers, Manchester.

4277.



The figure represents the cupola in position outside the foundry, with the metal spout F passing into the latter through an opening in the wall. The steam-pipe is taken up to the top of the cupola from a boiler, it is carefully lagged to prevent condensation, and terminates in a jet A, formed by a plain nozzle, similar to the jet-pipe in a locomotive chimney, the sectional area of the jet being fixed, as there is no necessity in practice for regulating the draught by any alteration of the size of the jet. The air is drawn into the furnace at the bottom through a series of circular openings, placed radially at two different horizontal levels. The lower circle contains four openings, or air-inlets, each 6¾ in. in diameter, and in the upper row there are eight air-inlets, each 3 in. in diameter. Each of these inlets has a cover, or valve, with which it can be closed from the outside if necessary. The charges are lifted to the door B, at the top of the furnace, and charging can be continued during the operation. Whenever it is intended to use a cupola for prolonged periods requiring continuous charging, it is preferred to provide the furnace with a feeding hopper having a sliding door opened and closed by a lever. The diameter of the cupola shown by the figure is 3 ft. at the boshes, total height 22 ft., and inside diameter of the cylindrical part 5 ft. The door at the bottom serves for cleaning the furnace and drawing out any materials remaining at the bottom after a charge is completed. In working, the furnace is charged with alternate layers of coke and iron, as is usual, the air-passages being all opened. Afterwards the draught is regulated according to the judgment of the founder, and care is particularly taken to close any single air-inlet opposite to which the iron is seen to accumulate in a semi-liquid state. The temporary interruption of the ingress of cold air at that particular spot soon allows the temperature to rise to the proper degree for making the iron run freely, when the admission of air can be recommenced.

The original shape of the Woodward cupola has been frequently altered by the inventors since it was first introduced. A recent and approved arrangement is a plain closed top, having a large gas-pipe leading off at the side, which pipe is carried down outside to the bottom of the cupola, and has the steam-jet applied to its bottom end. This arrangement has the advantage of cooling the gases down when drawn off, and thus reducing their volume, which gives a more favourable action to the jet.

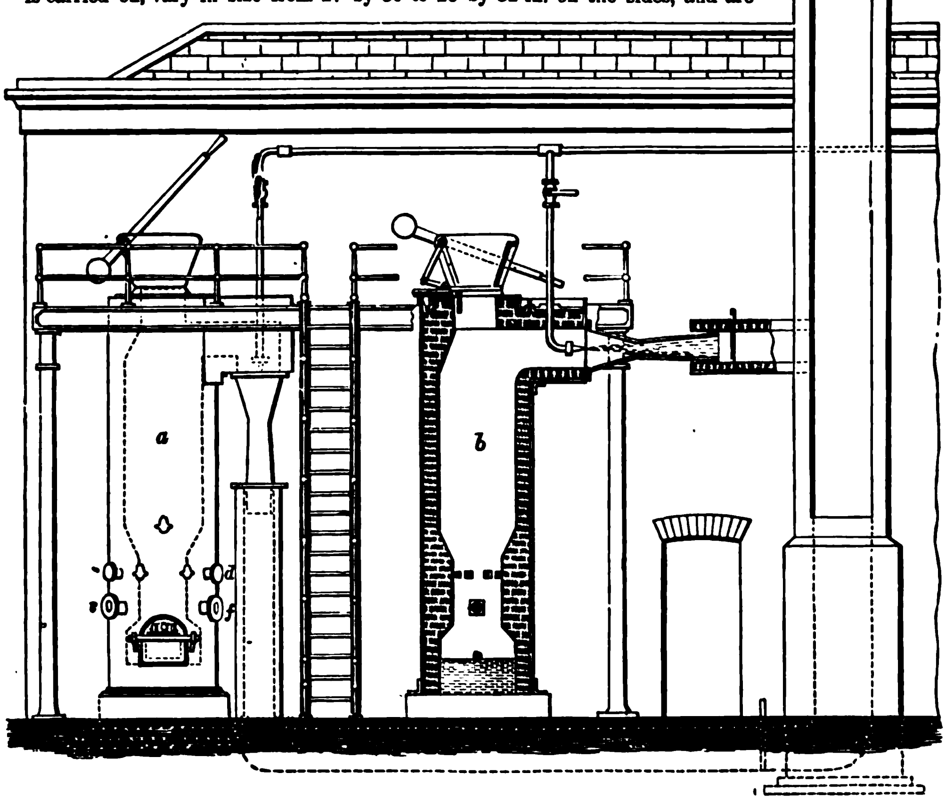
Fig. 4278 is of the cupola and feeding arrangement, showing an elevation at *a*, with gas-pipe and jet arranged for down draught, and leading into a flue under the floor, the feeding hopper being closed; *b* is a full section, and shows the horizontal flue leading direct to a chimney, the hopper open, and the charging stage with ladder.

Wrought Iron directly from the Ore.—We shall not allude to the ancient methods of converting ore into malleable iron; they possess only an historical interest, and accounts of them can be found in Percy's great work on the Metallurgy of Iron. The present mode of operation is represented in the American bloomery process. Although this was the system by which, in ancient times, all the iron made in England was obtained, it has long since been discarded in favour of less direct, but more economical, modes of smelting iron. A modification of the old bloomery process, however, still holds its ground in North America, where, in 1868, in Essex and Clinton counties alone, some 40,000 tons of malleable iron were made direct from the ore, to be consumed at Pittsburgh, in the

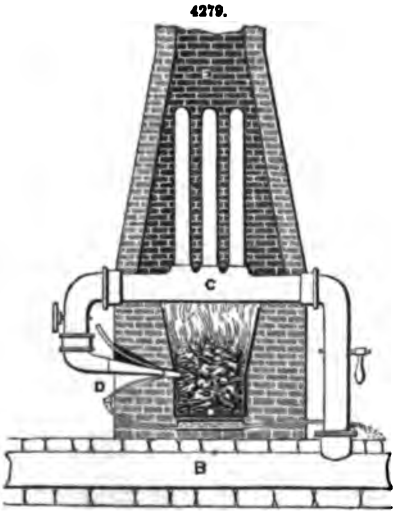
manufacture of cementation steel, for which this iron is eminently fitted. It is therefore believed that a description of the American bloomery process, as now worked in the States and Canada, compiled from the report of Dr. Sterry Hunt, recorded in the Journal of the Iron and Steel Inst. by David Forbes, F.R.S., may prove acceptable.

The bloomery hearths, or low furnaces, Figs. 4279, 4280, in which this process is carried on, vary in size from 27 by 30 to 28 by 32 in. on the sides, and are

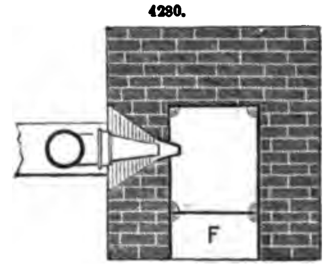
4278.



4279.



4280.



4281.

from 20 to 25 in. high above, and from 8 to 14 in. deep below the tuyere. The sides are formed of thick cast-iron plates, and the bottom of beaten clay or slag; or in the more modern hearths, of iron, cast hollow, so as to allow of their being kept cool by a stream of water circulating through them.

A is the hearth, B the blast-pipe from the bellows or fan, generally below ground, and C a hot-air apparatus of the form represented in Fig. 4281. The pipes are so

arranged that either hot or cold blast can be used. At D is a semicircular water-tuyere. The water, after being discharged here, is conducted in a pipe under the iron bottom of the fire, and confined in a separate box, from which it is finally removed to a drain. Through the front plate is a hole F, near the bottom of the fire; this serves for tapping of the superfluous cinders. E is a chimney for leading off the waste heat after having heated the blast-pipes.

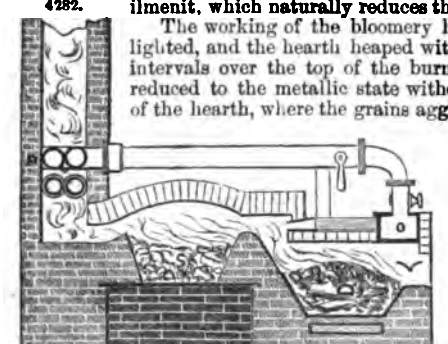
In the East Middleburg bloomery hearths the bottom plate is 4 in. thick, with an internal hollow space of 2 in.; the side plates, which slope slightly inwards and downwards, are 1¼ in. thick, and rest on the bottom plate. A water-box, 12 by 8 in., is let into the tuyere-plate, a stream of water circulating through it, and the bottom plate as wide as around the tuyere. The length of the hearth from the tuyere-plate to that opposite it is 24½ in., and the breadth from front to back 29 in.; its consequent area is 710½ sq. in. The tuyere enters 12 in. above the bottom, and is inclined downwards, so that the blast strikes the middle of the hearth; the tuyere orifice being a segment of a circle, 1 in. high by 1⅞ in. wide. In front of the furnace, 16 in. from the bottom, is placed a flat iron hearth, 18 in. wide: the side plate beneath it is provided with a tap-hole, through which the slag is drawn off from time to time. The iron plates last two years.

The bloomery hearths at the New Russia Works, at Moriah, have beds composed merely of beaten down earth or ashes. They are 24 in. deep, and the hearths have a superficial area of 640 sq. in., measuring 20 by 32 in. at the top, but are somewhat smaller towards the bottom; the tuyere enters one of the narrower sides of the rectangle.

The blast employed in the American bloomeries has a pressure of from 1¼ to 2 lbs. to the square inch, except when the ore is in the state of fine sand, when it is found necessary to reduce the force of the blast to from ¼ to 1¼ lb. the square inch. The blast is heated by passing through cast-iron pipes placed in a chamber above the hearth. These pipes, which are 5 in. internal diameter and 1 in. thick, are in the form of inverted siphons, each limb being about 7 ft. long; the temperature of the blast being about from 500° to 600° Fahr. Besides enabling each hearth to turn out more iron in the same time, the employment of the hot blast is reported to effect a saving of about 20 per cent. in fuel, 300 bushels of charcoal being required to produce 1 ton of iron of cold blast, where 240 would suffice when hot air is employed. The quality of the metal is, however, considered to be deteriorated if too hot blast is used; and at the New Russia Works it is stated that the iron turned out red-short when too hot a blast was employed, which was never known to be the case with the same ores when using cold blast.

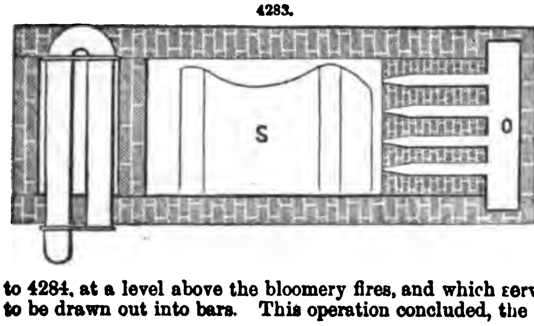
As in all other systems for the direct production of wrought iron from the ore, it is an essential point in the American bloomery process also that the ores should be as rich as possible in iron, such as magnetic ore, specular ore, crystallized red oxides, and some rich black or brown hematites, and it is desirable that they should not contain less than 50 per cent. When the ores contain much quartz or other extraneous mineral matter, they are, in America, calcined in lump, and after crushing, so as to pass through a sieve with openings of about ¼ of an inch, are washed until little but the native oxide of iron remains behind, unless in the case of the titanic iron ores, when, as in the Moisie Works, the washed sands still retain the whole of the titanic acid, in the form of ilmenit, which naturally reduces the percentage of iron contained in the worked ore.

4282.



The working of the bloomery hearths is conducted as follows;—The fire being lighted, and the hearth heaped with charcoal, the powdered ore is scattered at short intervals over the top of the burning fuel, and in its passage downwards becomes reduced to the metallic state without being melted, but accumulating at the bottom of the hearth, where the grains agglomerate into an irregular mass, the earthy matter in the ore forming a liquid slag, which is drawn off from time to time by the tap-hole. At the end of two or three hours, when a sufficiently large mass or *loup*, as it is termed, has formed itself, this is lifted by means of a bar from the bottom of the hearth, brought before the tuyere for a few minutes to give it a greater heat, and then carried to the hammer, where it is wrought into a bloom, the bloomery fire itself being used for reheating, or, more recently, an arrangement by which the waste heat from each pair of hearths passes into a sort of furnace, Figs. 4282

4283.



4284.

to 4284, at a level above the bloomery fires, and which serves to reheat the blooms, and enable them to be drawn out into bars. This operation concluded, the addition of ore to the hearth is resumed,

and the production of iron is thus kept up with but little interruption. In this way a skilled workman will, with a large-sized hearth, turn out a bloom of 300 lbs. every three hours, and, in some instances, even more than 1500 lbs. have been turned out in the twelve hours.

Referring to Figs. 4282 to 4284, V is the bloomery fire, from which the flame is conducted over the sand-hearth S, which heats the blooms or bars, and is then conducted to heat the blast in the pipes P. These pipes are straight and walled in the chimney. At O is a set of blast-pipes · these furnish heated atmospheric air to the waste heat from the fire, and burn any carbonic oxide which may escape from the fires. In order to obtain sufficient heat for the stove S, two fires are sometimes arranged, so as to supply their waste heat to it.

At the works of Messrs. Rogers, of Ausable Forks, twenty-one fires were in operation in 1868. The ore was the magnetic oxide of iron, mixed with quartz and felspar. After being slightly roasted, to render it friable, it was stamped, so as to pass through screens with openings of about ¼ of an inch, and then concentrated by working. Two tons of the worked ore, equivalent to form 4 to 5 tons of the crude ore as it came from the mine, was required to make 1 ton of blooms.

At the New Russia Works, in Moriah, near Port Henry, a nearly pure magnetic oxide of iron is employed, 3 tons of the ore yielding 2 tons of blooms. As perfectly pure magnetite contains only 72 per cent. metallic iron, the above proportion (66·6 per cent.) shows great economy of working, considering the nature of the process. The dimensions of the hearths used at these works have already been given. The pressure of the blast varies from 1¼ to 1¾ lb. to the square inch, and the average produce of iron for each fire was 2400 lbs. blooms in twenty-four hours; the amount of charcoal consumed varying from 250 to 300 bushels to the ton of blooms turned out, and the weight of the charcoal from 16 to 18 lbs. a bushel.

At East Middlesburg, where the conditions are very similar, the estimated consumption of charcoal was 270 bushels to the ton of blooms, and the pressure of the blast was from 1¾ up to 2 lbs. a square inch.

The cost of producing a ton of blooms direct from the ore depends greatly on the price and richness of the ore. In 1867 the 2 tons of dressed ore required to make 1 ton of the fine Ausable iron was estimated at 18 dollars, whilst the 1½ ton of ore consumed at the New Russia Works would probably not cost 9 dollars. An estimate made by a competent ironmaster shows the cost of producing iron in New York in 1868 as follows

2 tons ore .. .. .. dollars	10·00
300 bushels charcoal at 8 cents	24·00
Wages	9·00
General expenses	3·50

Cost of the ton of blooms, dollars 46·50; currency = 37·20 gold.

The above prices are in American currency, which at that time was equal to about $\frac{80}{100}$, making the gold value 37·20 dollars. The estimate of another manufacture in Clinton county gave 7 dollars for wages, and it will be observed that the quantity of charcoal taken into the above estimate exceeds the average, which may be calculated at about 270 bushels.

This mode of manufacturing wrought iron is a variety of the so-called Catalan method, which is conducted with the most ancient form of forges for making iron, and is still practised in some parts of Europe. In those instances we find the fire or hearth formed of sandstones, and protected by heavy charcoal dust. Cast-iron linings are not often met with. By these means coal may be saved; but it causes a greater loss of ore than bloomery fires, and more labour.

German Forge.—Grey or white pig iron is converted into blooms in bloomeries similar to those above described. A difference in the size and form of the hearth and its lining, position of the tuyere, and manipulation, is made in the German forge in cases where grey pig iron, white pig iron, or plate metal is worked.

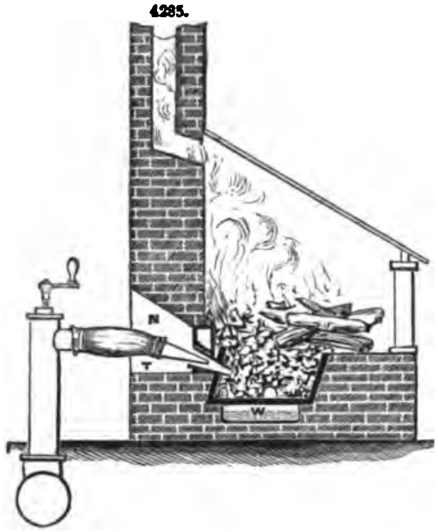
Fig. 4285 is a vertical section of a German forge-fire. The only difference between this fire and the bloomery-fire is, that the bottom is not so deep; it ranges from 6 to 10 in. below the tuyere, and the cast-iron linings are more or less inclined, which facilitates the operation and saves fuel. The tuyere T is, according to the kind and quality of crude iron, more or less inclined, and projects into the fire some inches. A water-tuyere with solid bottom is most generally used. The nozzle N is made of light sheet iron attached to a leather bag, and by that means to the blast-pipe, so as to be easily moved and directed to those parts in the fire where it works slow and where blast is needed. Fig. 4286 shows a plan of the fire, two of which are frequently attached to one chimney. Most modern fires have each a light chimney constructed of bricks; it has no other office to perform than to conduct the smoke and gases out of the building; and as the temperature in it is very low, it ought to be spacious, at least 4 sq. ft. in area for each fire.

The form of the hearth is the only important object in this apparatus; all the other parts may assume any form whatever, without any injury to the success of the operation. The blast should be dry, and from ½ to 1 lb. of pressure is necessary; 150 to 300 cub. ft. a minute for each fire are essential to carry on the operation.

The form of the fire is an oblong, 24 × 26 in., and from that to 25 × 32 in. in the clear. The cast-iron linings are plates of 1¼ to 1¾ in. in thickness, and firmly wedged together so as to resist the disturbance which may be caused by the use of the tools. The iron plate at the tuyere is inclined towards the fire from 8° to 10°; the opposite plate is not quite as much inclined from it. Front and back plates are generally plumb, or inclined from the fire; the first is provided with a 2-in. circular hole near the bottom, for the discharge of slag. The bottom is formed of a cast-iron plate 2 in. in thickness, which is kept cool by the water-box W, Fig. 4285. In some instances the water is directed under this bottom plate, without the box, which causes the bottom frequently to break. The upper edge of the plates for the fire, and consequently the whole hearth, is from 15 to 18 in. above ground. The inclination of the tuyere, the inclination of its plates, and the slope of

the bottom, are the most important subjects to be considered by the smith in constructing it. These are not the same in all instances. They are regulated by the quality of the crude iron, the iron to

4285.



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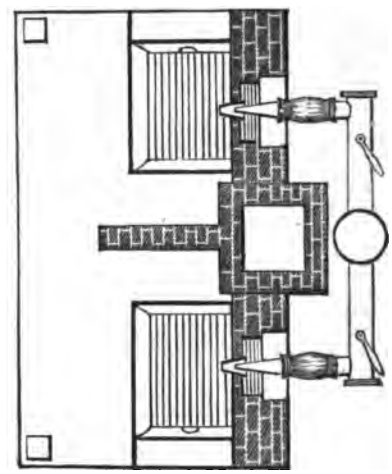

be manufactured, quality of coal, and the views of the workmen. Here, as well as in all other cases, the foundation of the hearth must be dry, so that no moisture may approach the fire.

The operation in these fires is very simple; with some experience, good iron may be made from any kind of crude iron. When the apparatus is well dried by a slow fire, the hearth is filled with charcoal and a gentle blast applied so as to kindle all the coal and heat the plates, which are protected by a heavy layer of charcoal dust. Hard charcoal, not of too large size, about that of an egg or a fist, is preferable to soft charcoal; it bears a stronger blast and works faster. Either previous to kindling fire, or when in blast, the bottom is covered by throwing on good rich slag from previous refinings, namely, that obtained by reheating balls or blooms. A cover of at least 2 in. in thickness should be on the bottom, and more than that when grey pig is melted. When the fire is thoroughly ignited by applying about one-third of the full blast, or 150 cub. ft., blowing with a nozzle and tuyere of 1¼ in. diameter, the pig iron is charged; from 200 to 300 lbs. being charged at once, or added gradually. When plate iron is charged, the latter mode is applied; if grey pig, the former. But there is no rule for this; one refiner adopts one plan for all kinds of crude iron, others make a distinction. Grey iron requires less blast and less heat than white iron, a shallow hearth, and more dip of the tuyere; the bottom is also more inclined towards the front than when white or plate iron is to be refined. A slope of 3° for the bottom may be considered the extreme adapted for very fusible iron. We must classify crude iron according to its fusibility, and not its colour, for impure white iron may work far slower than pure grey iron; and when we here use the term grey iron, or white iron, we refer to the fusibility of the iron, not to its colour. In describing the manipulation, we will treat of the two extremes, the working of grey iron and of plate iron. The bulk of crude iron used, and which forms the varieties, is worked between these two modes of manipulation.

Grey pig iron is melted in at once, by applying a very low heat; the broken pigs may therefore be placed above the tuyere; it ought not to be quite fluid when it arrives at the bottom. Either while the iron is thus melting down, or when it is all at the bottom, and after it has been gently stirred by means of a crowbar, the floating cinder is tapped off and thrown away. It is of no use, and contains most of the injurious impurities. If the iron is still fluid, some hammer-scales are thrown on it, and a stronger blast directed upon it; it is then stirred, and the resulting cinder is tapped and thrown away. When thus made more coherent, the iron is broken up, lifted from the bottom, and heated in parcels before the tuyere. The still crude iron now melts again, and on arriving at the bottom begins to boil. If it is now diligently stirred, by means of an iron bar, under an increase of blast, it gradually gathers into lumps; when in this condition, the cinder is again tapped off from the iron and saved. The mass is now tough, and assumes the nature of wrought iron. Under an increase of blast, this iron is turned about, thoroughly heated on all sides, and gradually converted into one or more round balls, which are now brought to the tilt-hammer and shingled down into blooms. All this time the fire is well supplied with coal, and the blast increased to its full force on the finished loop. If the iron is very impure and fusible, it will require a great deal of labour and the use of much coal; still, the yield cannot be expected to be high, particularly when a good quality of iron is to be made. As much as 250 bushels of coal may be consumed on weak pig iron; four hours' work is required on a heat, and 30 per cent. of iron may be lost.

White iron, or plate iron, is worked on a different plan. The basin of the hearth is deeper than for grey iron, the tuyere does not dip so much, the blast is stronger from the beginning, and the work commences as soon as melted iron arrives at the bottom. This kind of iron is never very fusible, and if it is fluid it does not long remain so after being exposed to the effect of the blast. The purer and stronger the iron is, the more it is inclined to coagulate. So soon as it is partly

melted, it is lifted from the bottom, brought before the tuyere, and by turning it about it is heated and refined on all sides. Those parts which do not resist the strong fire, melt down again and are taken up a second time. A number of small balls are thus formed, which, on being exposed to an increasing heat, are welded together and formed into a large ball of 100 or more pounds, which is brought under the hammer for compression. The work on this kind of iron proceeds faster than with grey iron, less coal is used, and the yield is far better. In two hours 300 lbs. can be heated, and a ton of iron by the use of 120 bushels of charcoal, and from 85 to 90 per cent. of iron yielded from the crude plate iron. One fire will easily produce from 4 to 5 tons a week, while from grey pig iron not more than half that quantity can be obtained.

We have detailed the methods just described, as they are of great service where the requisite minerals and fuel are plentiful, but where the demand for metal is not sufficient to justify the outlay for erecting a blast furnace, or when capital is scarce. The methods of making wrought iron by similar means are innumerable, but the variations are chiefly caused by the quality of the crude metal and the quality of iron to be produced.

Refining Cast Iron.—In the manufacture of the finest qualities of wrought iron refining is universally adopted, but with the inferior kinds it is not so much employed as formerly.

The refinery furnace, Figs. 4287 to 4289, usually consists of a cast-iron framework, surmounted by a short brick chimney. The bottom frame rests on a brick or masonry bedding, upon which is laid a floor or hearth of dressed sandstone, 10 or 12 in. thick. At each side and at the back, within the vertical frames, cast-iron waterblocks are fixed, and a castiron dam-plate, Fig. 4289, in front, the whole forming a quadrangular space about 4 ft. square inside, by 15 or 18 in. deep. Above the side blocks, and resting on a ledge cast for their reception, are fixed tuyere-plates, 2 to 3 in. thick, having openings for the insertion of the watertuyeres, and bolted fast at the ends to the vertical frames. The space between the tuyereplates and the top frame which carries the chimney is fitted with stout cast-iron plates, bolted at the ends to the vertical frames. In front, resting on the dam-plate, it is usual to have a dust-plate for the convenience of filling and working the fire. At a height of a few inches above this plate in front, and also above the rear waterblock, cast-iron doors,

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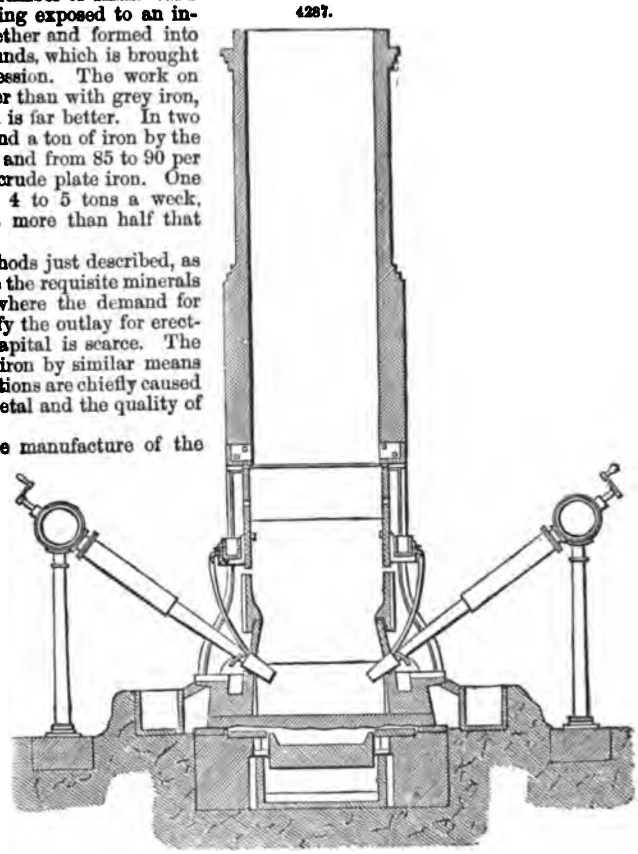

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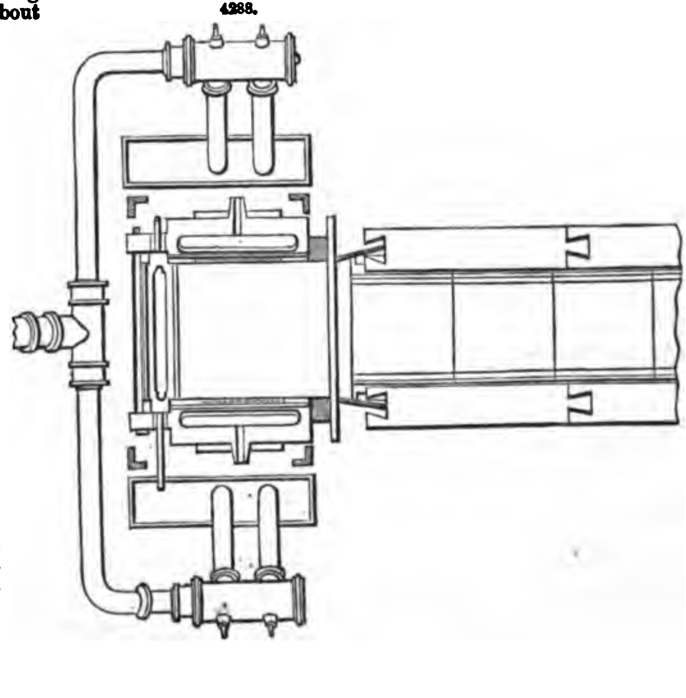
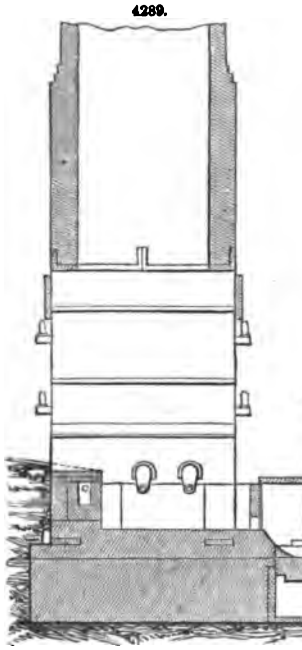


Fig. 4290, about 2½ ft. high, are hung to the side frames. Through these doors the working operations are carried on.

At a sufficient distance below the inside floor of the refinery, and a few inches in advance of

4289.



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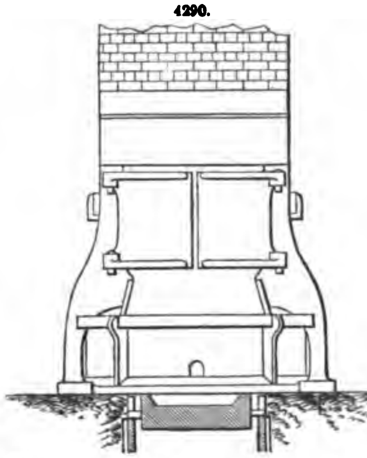


4291.

4292.

the dam-plate, the casting bed or pig-mould is constructed. A brick, or what is better, a cast-iron cistern, about 30 ft. long, 4 ft. wide, and 2 ft. deep, forms the substructure. The casting bed is composed of thick cast-iron blocks, about 3½ ft. wide, the same in length, and 6 or 8 in. thick, having flanges at each side to rest on the edges of the cistern underneath, and sloping flanges on the upper surface, to restrain the fluid metal within the desired limits. When in working order the cistern is filled with water to within an inch or two of the mould-blocks, and is maintained at this level by a small stream, the superfluous water escaping by an overflow notch. The jointing of the mould-blocks to each other is done with care, that no metal may penetrate into the cistern below; a thin stratum of fire-clay between them generally suffices for this purpose. The blocks are maintained in close contact by stout clamps taking hold of corresponding snags cast on the sides of the moulds.

The mould-blocks, Fig. 4291, are also made with a flange running down the centre, dividing the plate of metal into two widths; and to reduce still further the labour of breaking it up they are sometimes constructed with longitudinal grooves for receiving the metal, the dimensions and length being very similar to those of the moulds prepared in the dust-bed of the blast furnace for forming the original pigs.

The blowing arrangements usually consist of two or three small nozzle-pipes, Figs. 4287, 4289, at each side. Each pipe is furnished with a suitable stop-valve for regulating the supply of blast. The connection between the metal nozzle-pipe and the fixed blast-pipe containing the valves is generally made by a leather bag fastened at the ends around the pipe by screw clamping glands. The leather bags, however, may be dispensed with, and their place supplied by telescope pipes having a cup-and-ball joint, Fig. 4292, as a provision for any variation that may be required in the lateral and vertical direction given to the blast.

Refineries are also constructed with a single pipe at the back; the framework, water-blocks, mould, and other parts, are then of a lighter description, and the fire is altogether of much smaller dimensions. Other refineries are constructed with two and sometimes three pipes at the back. They are known as single refineries, while those having two sets of pipes, one on each side, as in the fire we have described, are known as double refineries. The double fires are generally blown with two or three pipes on each side, but four may be seen at some works.

Refineries are also distinguished as melting-down and running-in fires. The former melt cold pigs from the blast furnace, old castings, and scraps, while the latter work on hot fluid metal run direct from the blast furnace.

The melting-down refinery is usually in a building by itself at some distance from the blast furnace. The running-in fire is erected immediately contiguous to the blast furnace, from which the crude iron, on being tapped, flows into it.

The operation of refining crude pig iron is conducted nearly as follows;—The floor of the fire is strewn with some broken sandstone, and a fire is lit in the centre. A quantity of coke is filled in, and a light blast directed upon it. A charge of pigs, scraps, or broken castings is next placed on the ignited coke; a fresh charge of fuel is heaped on the pigs, and the full power of the blast brought into action. The weight of pig iron or other metal charged will vary with the size of the

fire, but may be taken at 2 tons, and the coke for the same at 5 cwt. An intense heat is soon produced; the broken sandstone on the floor melts, and glazes the surface of the hearth. In the course of about an hour the metal begins to melt, dropping through the coke to the hearth; in about two hours or two hours and a half the whole of the iron is melted and lies under the coke. The blast is still kept up, fresh coke is added, and the metal heaves and boils from the evolution of gases. The process is continued until the whole being sufficiently decarburized, the fluid metal is tapped into the cast-iron mould-bed. To render it more easy of removal from the mould, small dams of cinder are placed across at convenient distances, thinning the plate metal at such places sufficiently to render its separation easy.

The iron and cinder escape together from the refinery into the mould, but from its inferior specific gravity the great body of the cinder rises and collects on the surface of the plate. This separation of the metal from the cinder is stimulated by throwing water on the fluid metal immediately that the entire charge has left the refinery. The sudden cooling caused by the water renders the metal very brittle, and facilitates its subsequent breakage into pieces fit for the puddling process.

The time occupied in the operation of refining each fireful will average about three hours. White forge iron is not blown so long as grey pigs; the latter often require three and a half to four hours to be properly refined. Castings take still longer; the large and irregularly-shaped pieces to be melted frequently require nearly twice the usual quantity of blowing to effect their reduction.

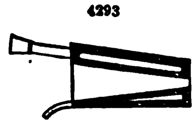
With the running-in refinery the operation is different, since the metal is charged, or more correctly speaking, run into the fire in a fluid state; hence the time occupied in melting it is saved. These fires are consequently enabled to refine a larger quantity in a given time, and are also worked more economically in their consumption of labour and fuel than the others.

A few pounds of the cinder from previous refinings are added in operating upon such irons as are smelted with less than the usual proportion of cinder in the blast furnace. By the addition, in moderate quantities, of a good cinder the work is hastened and the yield of iron improved. In this, as indeed in every other operation, the presence of cinder in moderate quantities is highly beneficial; when it is produced in small quantities the operation becomes more difficult, the quality variable, and the yield generally bad.

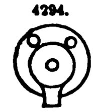
The bottom of the hearth, from the intense heat of the fire and the force of the blast being directed on it, is burnt away in a short period, and usually requires repair once a week. Brick bottoms are used at some works; and the practice of repairing the hearth by covering it with a course of bricks weekly is also practised to some extent. For durability, however, a sandstone bottom of millstone grit is superior to all others.

For conveying the blast into the hearth small wrought-iron tuyeres, Figs. 4293, 4294, are used, having their smaller orifice 1¼ or 1⅜ in. diameter, and the larger 3½ or 4 in. A ¼-in. or ⅜-in. pipe is screwed into the upper end as an inlet-pipe, and a similar one as an outlet for the water. The inlet-pipes are connected with a small cistern, placed 3 or 4 ft. above the tuyere; the outlet-pipes discharge the water into the side blocks, from which it enters the rear block, and finally is conveyed by a small pipe to the cistern under the mould-bed.

4293

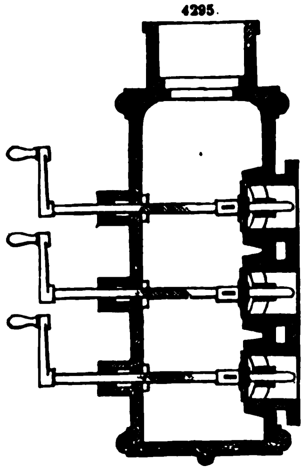


4294.

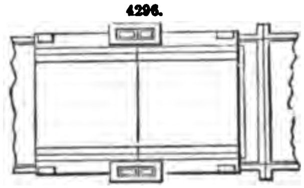


The nozzles of the blowing pipes, in double refineries, where four are employed, are usually 1⅜ in. diameter, or if of another section, are equal in area to a circular pipe of this size. A pipe flattened at the point, so as to increase the horizontal surface of action, is considered by some refiners as superior to the circular form. The angle which the direction of the issuing blast makes with the bottom is a matter of some importance. The best

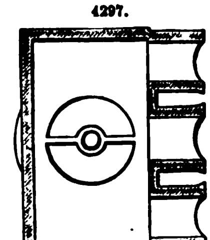
4295.



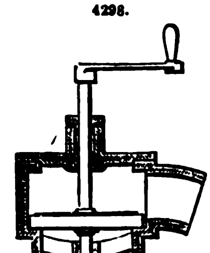
4296.



4297.



4298.

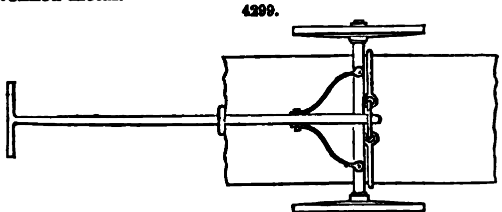


results have been obtained when the line of the blast makes an angle of 38°, and the angle enclosed by the two streams of blast 105°.

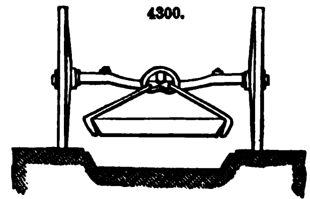
Fig. 4295 is a section of a blast-valve box, with three separate valves for three tuyeres; Fig. 4296, a pig-mould, jointed with clips; Figs. 4297, 4298, sections of blast-valve box, for three

tuyeres with simple valve; Figs. 4299 to 4301, pig of refined metal, on cart commonly used to remove it; Fig. 4302, pig-mould blocks, with double-rabbeted joints; Figs. 4303, 4304, two-handed sledge for breaking refined metal; Figs. 4305, 4306, scraper; Fig. 4307, spanner for breaking refined metal.

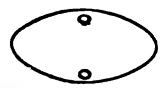
4299.



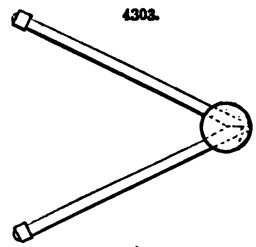
4300.



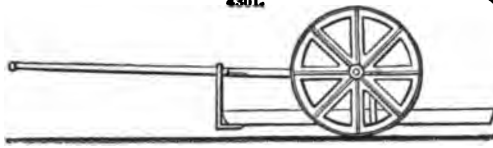
4304.



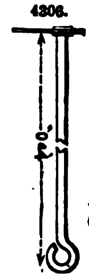
4303.



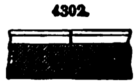
4301.



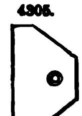
4306.



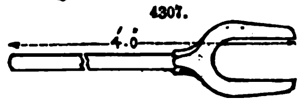
4302.



4305.



4307.



Theory of the Refining Furnace.—The operation of refining is a combination of chemical and mechanical processes, by means of which the metallic alloy is deprived of a portion of the extraneous matters contracted in the blast furnace. The crude iron contains various substances in mixture; generally the most important consist of carbon, silicon, and aluminium, as will be seen by referring to the analyses. It is the province of the refiner to extract from it the larger portion of these impurities preparatory to its conversion into malleable iron.

For this purpose the crude iron is fused in the refinery fire, along with coke or charcoal, as before described, and there kept at a liquid heat for a short period by means of numerous small jets of air. In the blast furnace the atmospheric air delivered through the blast-pipe is required for the maintenance of combustion. In the refinery the blast answers a double purpose. It creates and maintains an intensely high temperature, fusing the crude iron with great rapidity, and promotes the rapid oxidation of the impurities. But in this process a considerable quantity of metal is also oxidized, and this, in combination with a portion of earthy matter, forms the refinery cinder. Hence, of the oxygen of the blast delivered into the refinery, the larger volume unites with the carbon of the fuel, forming carbonic acid, and ascends into the atmosphere—a minor volume combines with the metal oxidized, forming oxide of iron (still another portion unites with the carbon contained in the molten crude iron, forming also carbonic acid, and escaping in a similar manner), while the remainder unites with the other substances, forming silica, alumina, &c. The separation of the various impurities is further facilitated, as in the hearth of the blast furnace, by mechanical subsidence. Specifically lighter than the metal, they float on the surface, united in definite proportion with oxide of iron, and to a partial extent protect the lower stratum from further oxidation during the process.

The decarburization and consequent refinement of the crude iron may be effected by fusion and oxidation in reverberatory furnaces without the intervention of a blast; but, since the blast expedites the operation, and results in a superior yield for the same degree of refinement, it is generally preferred.

The fracture of the refined plate metal when cold is white and dense at the bottom, but is of a honeycombed or cellular structure at top. The depth of the honeycomb is affected by the quality of the iron and length of blowing. If the metal is from ordinary forge pigs, and the blowing has been conducted an average time, the depth will be from 1 to 1½ in.; but if the plate is from good grey pigs, it probably will not exceed ½ in. By the reduced depth of the honeycomb and the bright silvery lustre presented by the metal, the general quality of the pig iron used in its manufacture may be pretty accurately determined.

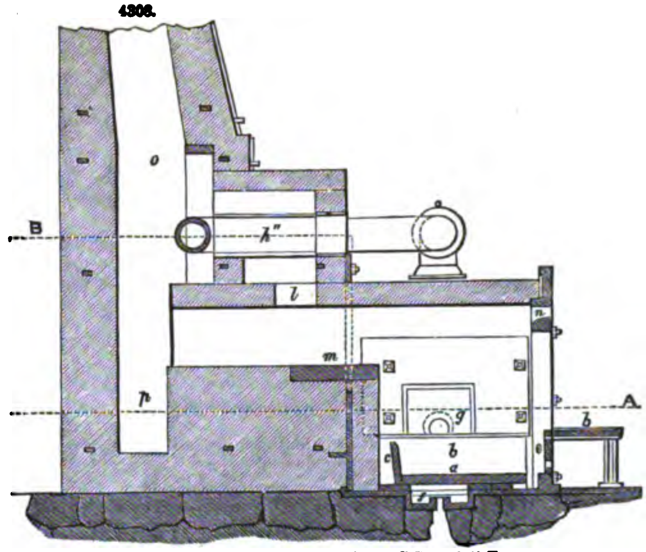
Charcoal Finery, or Lancashire Hearth.—We are indebted for the following accurate account of this important finery to Dr. Percy, who gives it in his work on Iron and Steel;—

The furnace, Figs. 4308 to 4310, consists essentially of a shallow quadrangular hearth, formed of cast-iron plates *a*, *b*, *c*, *d*, and *e*. The hearth bottom *a* is horizontal; the tuyere side *b* slightly inclined inwards; the opposite side *d* and the back *c* inclined outwards; the front *e* is vertical, and in it there are three round holes for tapping off the cinder. Under the hearth bottom is an open shallow cast-iron box, having a gutter on one side *f′*, and a round hole in the centre of the bottom *f*, surrounded with a border not quite so high as the box is deep; the box and gutter are cast in one piece. During the working of the furnace, cold water is continually flowing through *f′*, and running out at *f*. By this arrangement the hearth bottom is kept cool. The side walls above

the hearth are protected within by cast-iron plates, Figs. 4308, 4309. Hot blast is used, and there is one iron water-tuyere *i*, nearly semicircular in section, which passes through a thick cast-iron plate set in one of the side plates *g*. The narrow end projects over the side of the hearth ⅜ in., and the axis is inclined at an angle of about 10° with the horizon. As the charcoal is piled round and above the tuyere, the plate *g* is exposed to great heat, and consequently destruction; it is made very thick, and may be readily replaced when required. In front of the hearth is a table or platform of cast iron *h*, resting at the ends on cast-iron standards. This table is essential for the necessary manipulations. The arrangement for heating and conveying the blast to the tuyere is represented by *k*, *k'*, *k''*. The heating apparatus consists merely of a siphon-pipe of cast iron, set horizontally and exposed to the waste gases of the furnace. There is a throttle-valve at *k* for stopping and regulating the blast. The nozzle end of the blast-pipe may be raised or lowered at will by a telescope sliding-piece, and may be turned in any direction by means of the union joint below *k*, Fig. 4310. The waste gases escape partially through the square opening *l*. At *m* is a cast-iron plate on which pigs or blooms may be laid, so as to become heated. At *n* is an opening through which an iron bar may be introduced to move the objects on the plate *m*, or clean the arched passage leading from this part to the stack *o*, to which at the bottom is often attached a large chamber destined to intercept sparks. There is an ash-pit *p*, from which the ashes may be removed through an opening at *p'*, which is closed with a cast-iron door.

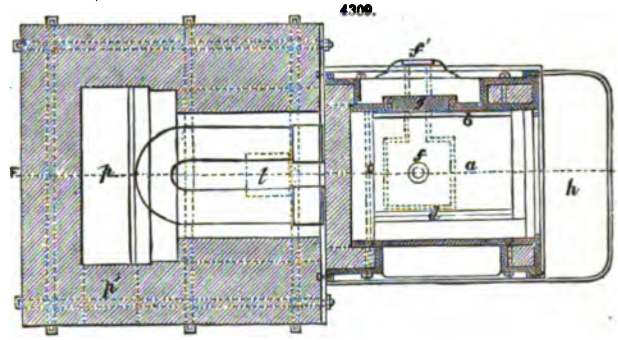
All being in working order, and the ball obtained in the previous heat removed, charcoal dust is spread out on the fore side, and the hearth is filled with clean charcoal. The pig iron, which is in plates 2 in. or 3 in. thick, and has been previously heated on the plate in the flue, is transferred to the hearth, the charge being 200 lbs. Fresh charcoal is added and the blast turned on, when, in about half an hour, the metal will have completely melted down, and in dropping through the blast from the tuyere have become partially oxidized. By the action of the oxide of iron thus formed, and of the basic silicate of protoxide of iron remaining in the hearth at the close of the last operation upon the molten pig iron, the latter is decarburized to a considerable extent, and,

4308.



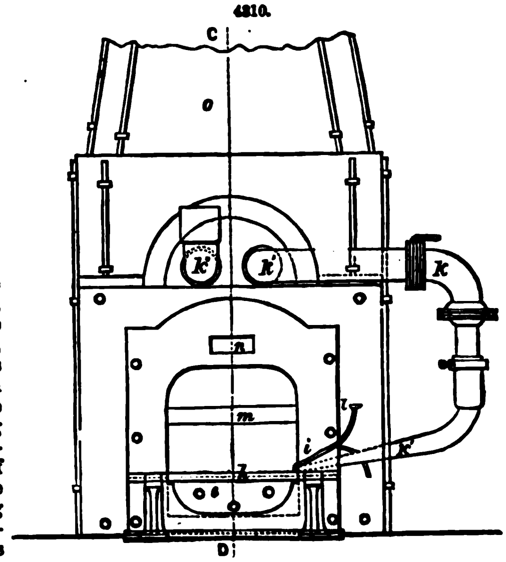
Longitudinal Section on lines C D and E F.

4309.



Horizontal Section on line A B.

4310.



Front Elevation.

in consequence, becomes less fusible and more pasty. After perfect fusion of the metal, the refining proper begins. This consists in incessantly breaking up the metal with an iron bar, and carrying towards the tuyere the raw portions, which, being more highly carburized, and more fusible than the rest, always run down to the bottom, and there harden. The metal, which has thus more or less solidified, is broken up and submitted to the action of the blast until all is sufficiently refined; this operation lasts about half an hour. Subsequently all the metal is brought up to the top of the hearth, and again melted down with a lively heat to form the ball, fresh charcoal being thrown into the hearth, and the unmelted portions being kept up at intervals with an iron bar to prevent their adhering to the ball before having been melted. The ball is then taken out and hammered into a prismatic shape, which is cut into pieces to be welded in another fire. The whole process lasts from 1¼ to 1½ hour.

The blast is frequently used at a temperature of 100° C., and at a pressure of 2½ in. of mercury.

The cut-up pieces to be drawn out under the hammer are welded and heated in hearths much resembling in size and construction the charcoal finery itself, or in an Ekman's furnace, now extensively used for this purpose.

Walloon process, employed at Dannemora, Sweden. The Dannemora irons have generally a fine grain, unequal in size, and composed apparently of hard and soft particles; but in ductility and tenacity the strength of this iron is very remarkable, it has the peculiarity that when heated it becomes very soft and full of fibre; and when cemented and cast into steel, the inequalities of fracture entirely disappear.

The hearth in the Walloon process is composed of cast-iron plates. The bottom plate is 2 in. thick, and underneath is a strong bed of pounded slag about 3 in. in depth, which rests upon a cast-iron box provided with suitable channels to drain off water. The tuyere side plate inclines somewhat into the hearth, and the opposite side plate, on the contrary, considerably more outwards. From the centre of the tuyere to the back plate the distance is from 10 in. to 11½ in., and to the commencement of the work-plate it is from 22 in. to 24 in. The front of the hearth is enclosed by a brick wall, within which is the fore plate inclining outwards, and on the top of which the work-plate lies horizontally. This wall is a little higher than the back wall, and does not contain any tapping hole, as the slags are never let out. From the tuyere side plate, on a level with the tuyere, the distance to the opposite side plate is from 22 in. to 24 in. The axes of the tuyere and blast-pipe are at right angles to the tuyere side plate; and as this inclines forward a few degrees into the hearth, they have the same inclination. The nozzle of the tuyere is semicircular, with the flat side at the bottom; it is from 20 to 25 lines broad, from 16 to 17 lines high, and projects 3½ in. from the tuyere side plate. The nozzle of the blast-pipe is likewise semicircular, and is somewhat larger than that of the tuyere, so that it lies back within the latter 4 in. The depth of the hearth under the tuyere is from 7 in. to 8 in., under the upper edge of the back plate from 14 in. to 15 in., and under that of the work and adjoining side plate, opposite the tuyere, from 15 in. to 18 in. The fuel is fine charcoal, and this hearth works extraordinarily hot as compared with all others. Cold blast is used.

The iron employed is white or strong mottled, and is in long pigs about 9 in. broad, from 15 ft. to 18 ft. in length, and from 3 in. to 4 in. thick at one end, and from 1 in. to 2 in. at the other. The pig is placed at right angles over the back plate, with one end inclining downwards over the tuyere; and as this end melts, the pig is gradually pushed forward, so as to keep the end in the same position. Usually two such pigs are put one over the other.

The fore part of the hearth being filled with moistened small charcoal, and the remainder with charcoal, the fire lighted, and the blast let on, the pigs are pushed forwards; and in order to produce a sufficient bath of slag, some large finery-scraps, or several shovelfuls of hammer-slag, are melted down.

A peculiarity of the Walloon process is that at the beginning of the heat the bloom obtained from the last lump is held with tongs, as steeply inclined as practicable, in part of the hearth, and reheated preparatory to further manipulation.

The working with the iron bar or staff commences immediately after fusion of the first portions of the pig iron, and is regularly continued until the whole of the metal melted down on the tuyere side has been once brought up from the bottom and that side towards the middle of the hearth, and so exposed to the action of the blast. It is also worked once to the left and once to the right of the bloom undergoing reheating. The melting of the pig iron takes place pretty quickly, about 70 lbs. being melted in twenty minutes. Owing to the facility with which this kind of pig iron comes to nature, or arrives at the state of malleable iron, and the continual working with fresh staffs, the metal which has been fused is by that time so far refined that thin pieces of malleable iron will be seen adherent to the staff. The whole of the molten metal is now completely broken up above the tuyere, melted down, and formed into a lump; and during this part of the process the supply of fresh molten pig iron from above should obviously be stopped. The lump is about 12 in. broad and 15 in. long. The average period between the completion of one lump and another is twenty-eight minutes, the extremes being twenty-five and thirty minutes. Each lump is heated from six to eight times in the course of being drawn out into a bar 12 ft. long, and the weight of the bar from each lump is about 60 lbs. The shift lasts eight hours. Two finers and one assistant are required for each hearth.

It is evident that in this process the pig iron is exposed to conditions favourable to rapid decarburization by oxidation, namely, the small quantity of iron operated upon at a time, the comparatively large size of the hearth, the high temperature, the large amount of blast, the gradual melting of the pig iron drop by drop before the blast, and the almost incessant working of the metal.

Franche-Comté Process.—Franche-Comté is the name of an old province in the east of France, and the process has acquired its designation from having been long practised, if not originated, in that locality, whence it was imported into Germany and Sweden.

The hearth is composed of five cast-iron plates. All these plates are rectangular, except that of the tuyere side, which is occasionally not so high on the side of the back plate as on the side of the fore plate, in order that when there are two tuyeres the hind one may be set a little below the front one. The fore plate is from $0^m\cdot02$ to $0^m\cdot03$ (0·79 in. to 1·18 in.) thick, and the others from $0^m\cdot06$ to $0^m\cdot07$ (2·36 in. to 2·76 in.) thick. They last during several months, except the bottom plate, which must be renewed every week, and sometimes more frequently; but the hearth is so constructed that this renewal may be effected by simply taking down the fore plate.

The hearth should rest on a brick or stone foundation, covered with a layer of clayey soil well beaten down; and if there is danger of moisture, this may be completely avoided by setting it in a cast-iron box. In order to prevent the bottom plate from becoming too hot, in which case the fining process would be retarded, it is placed on a small iron frame, $0^m\cdot5$ (1 ft. 7·69 in.) long, by $0^m\cdot2$ (7·87 in.) broad, and $0^m\cdot27$ (1·07 in.) thick, so that by means of an old tuyere a little water may be made to flow into the space between this plate and the ground; but this should not be done until just after the lump has been taken out, for otherwise the great heat of the hearth might crack the plate.

The back plate is set between the tuyere side plate and the opposite one, and the fore plate also rests against these two plates, but standing upon the bottom plate. The back and fore plates are always fixed vertically. The tuyere side plate is sometimes vertical, and at others slightly inclined towards the interior, especially when it is intended to treat dark grey pig iron, which only melts at a high temperature, this inclination bringing the blast closer to and concentrating the heat upon the pig, which is pushed forward as in the *Walloon* process. The side opposite the tuyere is formed either of a single piece, always a little concave, or of two pieces of cast iron, one supported upon the other, the upper one resting upon a brick wall, and the lower one forming with it a very obtuse angle. Almost always this side leans a little inwards, in order to prevent loss of heat; sometimes it is quite vertical; and rarely it leans a little outwards, so as to facilitate the withdrawal of the lump when of very large size. The bottom plate is inclined both towards the side opposite the tuyere and the fore plate—an arrangement which is essential in order that the cinder may flow easily through the tap-hole situated on the tuyere side. This double inclination is given by means of small pieces of iron placed at the angles of the plate, or under the small frame on which it rests. The various plates are fixed most solidly together with wedges of iron. The hearths are preferably blown with two tuyeres. The tuyeres are of copper, and should last nine or ten months. With hot blast, cast-iron water-tuyeres are employed, but when the temperature of the blast does not exceed 200° C., copper may still be used, although they require more frequent renewal than with cold blast. The muzzle or eye of the tuyere is semicircular, $0^m\cdot027$ (1·07 in.) by $3^m\cdot024$ (0·95 in.), when the hearth is blown with two tuyeres. The eye has been made very flat, $0^m\cdot040$ (1·58 in.) long by $0^m\cdot010$ (0·39 in.) high, in order to compel the blast to spread in a sheet, and this has been attended with advantage. When there are two tuyeres they touch each other outside the hearth, but in the interior they are a little separated.

Most of the hearths are covered, either with an arched roof to prevent loss of heat, or by a flue conducting the waste flame into a furnace or an oven, where it is utilized.

Certain changes are made in these hearths according to the quality of the pig iron to be treated; they consist chiefly in increasing or diminishing the depth of the fire, the inclination of the blast, and the projection of the tuyeres into the interior.

Large-grained grey pig iron, with graphitic scales, is usually treated by this method, and only occasionally mottled and white pig iron. All the pig iron consumed is made from pisolitic iron ores, occurring either in the upper tertiary beds, or in deposits derived from those beds, and yielding from 33 per cent. to 36 per cent. of pig iron.

Manipulation.—The pig iron is supplied to the hearth exactly as in the Walloon, and gradually melted, the molten metal trickling down in drops through the strongly oxidizing blast. After the removal of the lump or ball in the last heat, the rich cinder which may have accumulated at the bottom is raised up; the bottom is well fettled with small charcoal, and the pig is then pushed forward over a roller, with its end inclining somewhat downwards. The pig ought to be so placed that the distance between it and the side facing the tuyere is only $0^m\cdot03$ (1·18 in.) or $0^m\cdot04$ (1·58 in.), in order to promote as much as possible the action of the blast upon the pig iron, allowing it, however, to ascend to the top of the fire. The bottom of the pig also should be $0^m\cdot1$ (3·39 in.), $0^m\cdot12$ (4·73 in.) above the stratum formed by the blast, and its extremity should not be more than $0^m\cdot06$ (2·36 in.) beyond the axis of the tuyere in front. In this position the pig melts drop by drop, and this is essential to success.

Before filling up the hearth with charcoal, pieces of rich cinder, intermixed with hammer-slag, are placed upon the pig on the side farthest from the tuyere. These slags, which quickly melt, are intended to form a bed upon which the metal dropping from the pig, during the whole period of fusion, should rest, as well as the bath of poor slag, which ought to cover the product of that fusion, and preserve it from the action of the blast. Moreover, when the hearth has been filled with charcoal, a shovelful or two of hammer-slag is thrown on the top. A finery of this description, when in good working order, consumes all the rich slag which it produces; only the poor, containing about 60 per cent. of protoxide, or 46 per cent. of metallic iron, being thrown away.

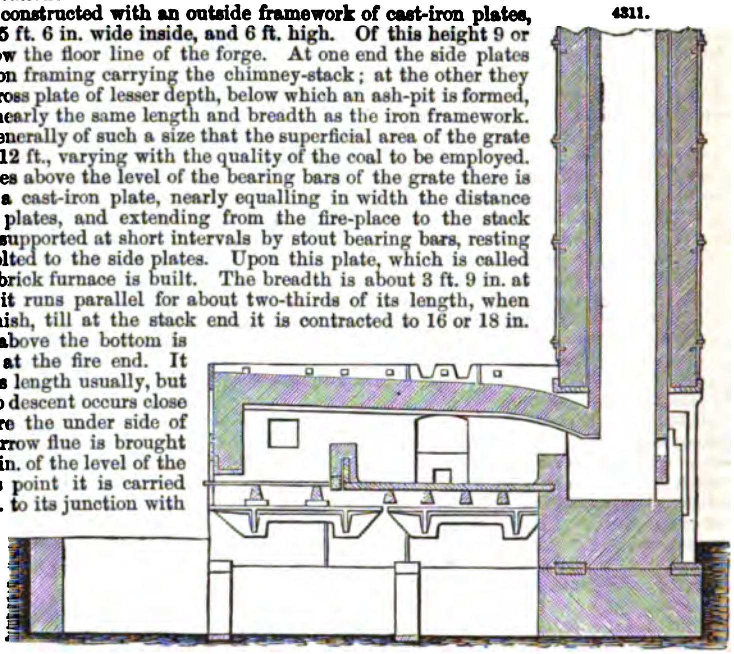
The ball is shingled or forged under the hammer into a bloom which is cut into two equal and similar pieces. During numerous heatings and reheatings under the tuyeres, occupying about 1½ hour, these pieces are separately forged each into a bar with two heads, and the forging completed by melting the four heads into one mass.

Boiling and Puddling Pig Iron.—In converting the crude iron of the blast furnace into malleable iron upon an extensive scale, two modes of procedure are open to the manufacturer, either to refine the crude iron in the finery fire, and then pass it through the puddling process; or, to put the crude iron through a modification of the puddling process termed boiling. Each method possesses certain advantages, but where quality is the sole consideration, the process of refining and puddling

is entitled to the preference. Upon the merits of the two systems ironmasters do not generally agree. By some the boiling process is held to be fully equal and more economical than refining and puddling; on the other hand, it is maintained that boiled iron is more subject to be red-short. In several works both methods may be seen in operation, but where this occurs the larger quantity of iron is first passed through the refinery. Hence, in such instances it would appear that while boiling a certain quantity of pigs is considered advantageous, it is not desirable that the manufacture of the entire quantity of crude iron should be conducted in this way.

Fig. 4311 is a section of a boiling furnace; Fig. 4312 a sectional plan; and Figs. 4313, 4314, front and back elevations.

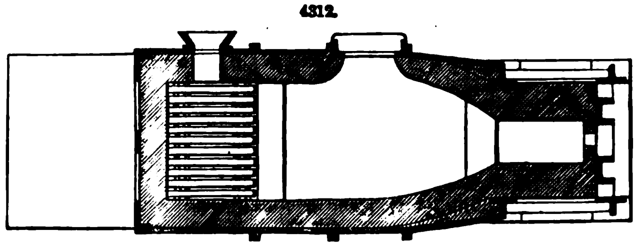
4311.



The furnace is constructed with an outside framework of cast-iron plates, about 12 ft. long, 5 ft. 6 in. wide inside, and 6 ft. high. Of this height 9 or 10 in. will be below the floor line of the forge. At one end the side plates are bolted to an iron framing carrying the chimney-stack; at the other they are attached to a cross plate of lesser depth, below which an ash-pit is formed, 2 ft. deep, and of nearly the same length and breadth as the iron framework. The fire-place is generally of such a size that the superficial area of the grate shall be from 8 to 12 ft., varying with the quality of the coal to be employed. Three or four inches above the level of the bearing bars of the grate there is fixed horizontally a cast-iron plate, nearly equalling in width the distance between the side plates, and extending from the fire-place to the stack framing. This is supported at short intervals by stout bearing bars, resting on angle-pieces, bolted to the side plates. Upon this plate, which is called the bottom, a fire-brick furnace is built. The breadth is about 3 ft. 9 in. at the fire end, and it runs parallel for about two-thirds of its length, when it begins to diminish, till at the stack end it is contracted to 16 or 18 in. The arched roof above the bottom is about 27 in. high at the fire end. It falls throughout its length usually, but in all cases a sharp descent occurs close to the stack, where the under side of the roof in the narrow flue is brought down to within 10 in. of the level of the bottom; from this point it is carried level for 9 or 10 in. to its junction with the vertical flue of the stack.

The length of the fire-place having been determined, a brick bridge, 14 or 15 in. thick, is built on the extreme end of the bottom plate, and carried up to within 10 or 12 in. of the roof. At the stack end, where the furnace is contracted to its narrowest dimensions, a second bridge of fire-brick, about 9 in. in thickness and 10 or 12 in height, is built to restrain the metal from flowing into the flue. When finished, the body of the furnace measures about 6 ft. long, 3 ft. 9 in. wide, by 2 ft. high to the centre of the roof. On one side a doorway, about 16 in. square, is formed, for charging and working the crude iron. The height of the bottom of this doorway above the bottom plate is of some importance. The average height at several works is 10 in., the lowest being 8, and the highest 11 in. As the height of this doorway is determined before casting the side plates, it regulates the height of the bottom and also of the roof of the furnace, especially at the end next the stack, where the general rule is to have the under side of the arch level with the lower side of the doorway.

4312.



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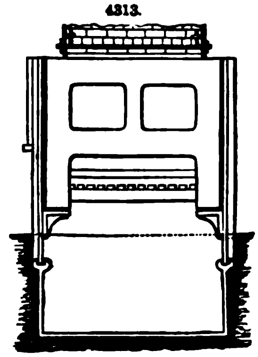

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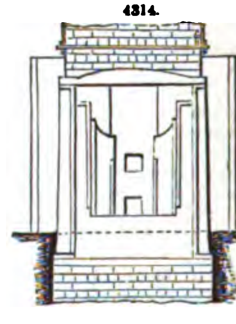


The metal forming the lower edge of the doorway is subject to wear by the constant pressure

and friction of the iron working bars of the puddler; to prevent this as much as possible a loose plate, Fig. 4311, about 1¼ in. thick, is bolted on to it, which can easily be renewed when necessary. The cast-iron door is lined inside with fire-brick, and is made to slide up and down between strong cast-iron flanges by means of a rod connected to a counterbalanced lever. For the convenience of working, and for the protection of the puddler from the intense heat, a small slit, about 3¼ in. wide by 5 in. high, is left in the under side of the door; through this the working operations are principally carried on. To prevent the sides and upper edge of this slit from being enlarged by constant wear, the metal around it is hardened by being cast in metal chills.

This, the working door, is situated rather nearer the fire-bridge than the flue. In the wall left on the side of it next the flue a second doorway of smaller dimensions than the working door is used for charging the metal, where this is done before the previous heat has been withdrawn. This charging door is usually about 10 in. by 13 in., and 12 or 13 in. above the bottom plate, having a lever and balance-weight for lifting it similar to the working door. Both are often used in boiling furnaces, but generally a single door suffices. In puddling furnaces, however, they are generally adopted.

A doorway, about 10 in. by 10 in., is also left opposite the fire-place; it has a cast-iron mouthpiece, but no door, the mode of firing rendering this unnecessary. At the stack end a small aperture, about 4 in. by 6 in., is provided for the escape of any cinder that may pass over the bridge into the flue. A small fire is kept burning over this aperture, in a grate secured to the outside frame of the stack, to keep it open for the passage of the cinder, and to maintain the latter sufficiently fluid.

The chimney-stack is built of fire-brick. For the generality of forge coals it is 30 ft. high above the cast-iron framework, or altogether 36 ft. The interior flue is made about 24 in. square, but at its junction with the roof of the furnace it is contracted to about one-third of this area. This contraction is regulated partly by the skill of the workman, but principally by the qualities of the coal. The size of the flue in this place is occasionally as small as 17 in. by 9 in., with a coal approaching nearly to the character of anthracite. With a more inflammable coal it has been 18 in. by 18 in. The chimney walls are usually built 1½ brick thick for 14 ft., 1 brick for 10 ft., and half a brick the remaining 6 ft. The intense heat in the chimney destroys the lower courses in a comparatively short period. To facilitate the repairs of this part a lining half a brick thick is carried up, without binding with the other work, for about 20 ft. When necessary this is drawn down and rebuilt without interfering with the stability of the stack.

The top of the chimney is surmounted with a light cast-iron framework fitted with a damper for regulating the draught. This damper is opened and shut by a lever, from which an iron rod or chain descends to the workmen below. A different mode of regulating the draught is sometimes adopted, but of this plan we shall have to speak hereafter.

The effects of the expansion and contraction of the brickwork by the alternate heating and cooling are provided against by numerous iron binders built in, the projecting ends of which are punched or cast to receive vertical wrought-iron rods, which are keyed up tight against the brickwork by iron wedges at their backs. Unless the light chimney-stacks were well bound together they would not long remain upright under the straining to which they are subjected. Imperfectly bound stacks may be seen in every work inclining at angles more or less dangerous to their stability.

The immense strain exerted by the expansion of the brickwork of the roof has also to be met by a number of strong wrought-iron bolts at the top and bottom of the side plates. For ordinary furnaces these should not be more than 2 ft. 6 in. apart when the bolts are 1¼ in. square. The plates may also be strengthened by vertical ribs on the outside face; if this be done the risk of their breaking in the middle—a very frequent occurrence—will be nearly removed. In some works the binding is composed of wrought-iron looped straps at top and bottom with vertical connecting bolts, also of wrought iron; by this arrangement the direct strain on the side plates is greatly reduced and their durability consequently increased.

The plate in which the doorway for feeding the fire is situated, commonly called the stock-hole plate, is the least durable of the whole. The stock-hole is usually a square with sharp angles; after a few weeks, sometimes only a few days, the plate breaks across one or more of these angles. This is doubtless caused by the unequal expansion and contraction of the surface, but a remedy has not yet been discovered. The angles have been rounded off without effect. In other cases wrought-iron looped clamps have been cast in the metal across, and at right angles to the general direction of the fracture, but without adding greatly to the durability.

The process of boiling is thus conducted;—The bottom of the furnace is covered with some broken cinder from previous workings, and mill scales, and a fire is lit in the grate. In from ten to twelve hours with new furnaces (five or six is sufficient with old), the interior of the furnace will be at a white heat, the cinder melts, and flowing over the bottom protects it from the fused iron and intense reverberatory action of the roof, and fills any crevices in the edges of the brickwork. The draught is now slacked a little, about 30 or 40 lbs. of cinder are charged at the flue end, and the quantity of pigs to be operated on, technically called a heat, generally 4¼ or 4½ cwt., is charged in pieces of convenient size—30 to 40 lbs. is best, and the more uniform the better. The charge is distributed upon the bottom of the furnace, the door closed, and the admission of cold air is prevented by throwing a little small coal or cinders around its edges, and filling up the notch with a lump of coal, covering it with a small iron plate. The damper is opened to its full extent, fresh fuel is added in the grate, and the fire is strongly urged. From the peculiar form of the roof the heated products of combustion are deflected on the pigs, and the extremity of the roof being placed low they are compelled to pass in close contact with the entire charge.

In about a quarter of an hour after charging, the puddler throws in about 60 or 80 lbs. of the cinder expelled by the rolls from mill bars; where these cannot be obtained recourse is had to the cinder from rolls, rolling puddled iron bars. The cinders which are drawn from under rolls

working on boiled iron are of inferior quality, and are never used in the boiling furnace if others can be procured. They contain a larger percentage of silica, and are less fluid; the time occupied in the boiling process consequently is lengthened whenever they are used, and it is believed with some reason that the quality of the resulting iron is inferior.

When the pieces of pig approach a red heat the puddler directs his attention to their position; those in the coolest parts of the furnace are shifted forward to the hottest, and those in the hottest to the coolest, the object being to bring the different pieces simultaneously to the melting-point. Unless this is accomplished the waste of iron and loss of time will be considerable.

The working door is now made fast by tightly wedging it into the frame. In from twenty-two to twenty-five minutes after charging, dependent in great measure on the quality of the coal, the edges of the pigs begin to melt; in another five minutes they are softened and apparently adhere to each other and the bottom. The puddler now raises them and turns them over to expose them equally to the heat and prevent their adhering together, which would obstruct their melting. At this stage it is common to charge two or three lumps of coal next to the flue-bridge, and about 15 lbs. of cinder for the protection of the brickwork in this quarter. Thus far the fire has been urged to its utmost power, the second-hand adding fresh fuel every few minutes and maintaining a clean grate and free draught.

In thirty minutes from the time of charging the iron is all melted, and the most laborious operation of the puddler commences. He puts in the rabble, and rakes up the fluid iron fore and aft, and raises the lower portions to the surface. At this point the energies of the puddler and his second hand are taxed to their utmost, both labouring at the raking up and stirring of the metal.

The fluid iron boils violently, and rises spontaneously nearly to a level with the lower edge of the door; its surface is dotted with innumerable eruptions, caused by the escape of gaseous matter. In five or six minutes after the boil begins the damper is partially lowered, checking the draught and reducing the heat within the furnace. The effect of this reduction of heat is immediately seen; the iron becomes evidently thicker and more pasty; now, too, it adheres to the tools, and has to be removed by a hammer. The raking up of the metal from the bottom is continued unceasingly; the small door is opened, and the parts next the flue turned over along with the rest.

This working of the boiling metal continues for about eighteen minutes, at the end of which time the fluid iron has the appearance of a quantity of dirty snow. The continual raking motion has resulted in the evolution of the carbon and the separation of the iron from the cylinder, which now flows over the bottom apparently as fluid as water.

The period for balling up now arrives; a few pounds of wet scales from the cooling bosh are thrown in. Their introduction causes an immediate reduction of temperature, which is increased by the puddler towards the end of the period of pasty condition desired. After eight or nine minutes' raking of the iron, now in the condition of pasty lumps, but which require to be constantly stirred to keep them from running back to the form of boiling iron, the puddler commences to form the puddle-balls. The number of these depends on the iron charged and the ability of the workman. Five or six is usual, but seven or eight may be seen brought out. The puddler commences by raking together such a quantity of the pasty iron as he conceives will suffice for a ball, and placing it a little aside in the furnace. He then proceeds with the remainder in a similar manner, keeping the iron together, and shaping his balls by the help of the leverage which he has with the iron bars, the slot in the door acting as a fulcrum. When the balls have been roughed out, the damper is nearly closed. This is done so that in the finishing of the balls the heat may not be such as to soften them and cause an unnecessary waste of iron.

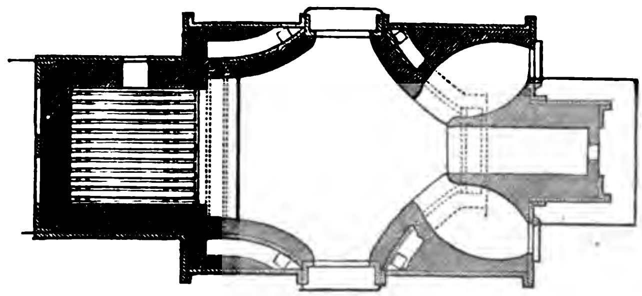
The puddle is now ready to *come out*, the wedges around the door are driven back, and the balls drawn. This occupies about four minutes. From charging the first piece of pig to the extraction of the last ball the time occupied will average, with good workmen and a fair coal, one hour and twenty minutes; but with inferior workmen and a less inflammable coal, one hour and fifty minutes is about the average. If it is performed in eighty minutes, as we have described, a puddler and his second hand will easily boil eight heats in the twelve hours, producing, with charges of 4½ cwt. each, 32 cwt. of boiled iron bars daily, or 9 tons 8 cwt. weekly, making, for the entire weekly produce of the furnace, working night and day, 18 tons 16 cwt.

On the withdrawal of the balls a quantity of cinder will remain on the bottom. A portion of this is tapped below the working door before charging a fresh heat. This cinder is produced by the oxidation of the iron and metalloids in alloy; it contains a large portion of silica, and, if not frequently renewed, will ultimately contain so large a quantity as to render it unfit for the protection of the iron. By tapping and replacing it by other cinder from the mill rolls, the puddler prevents the increase of silica, and ensures a fluid cinder rich in iron.

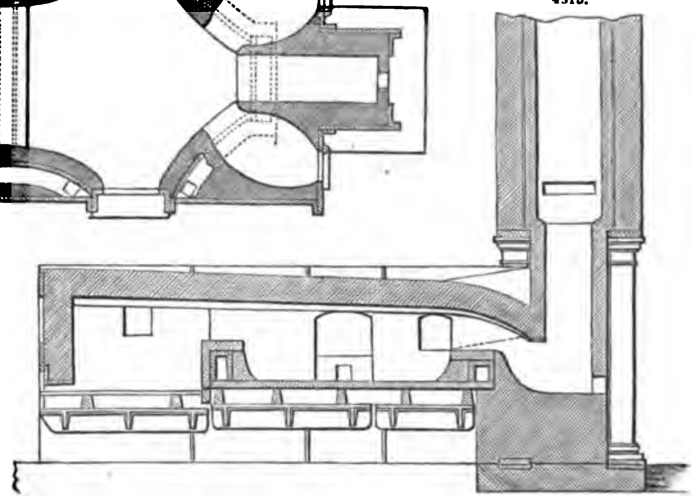
Boiling crude iron direct from the blast furnace is practised to a limited extent. By operating on fluid iron, the coal consumed in melting the cold pigs, amounting to one-third of the entire consumption, is saved, and the certainty obtained that all the iron is perfectly melted before the boiling commences, thereby ensuring the greatest uniformity in quality. Yet notwithstanding the acknowledged superiority of the boiling process in direct connection with the blast furnace and the period which has elapsed since the system was first adopted, the number of furnaces working on this plan is not large. The necessity of reconstructing the forge and bringing it inconveniently close to the blast furnace, is a great objection to its extensive use in existing works, while in the erection of new ones the contracted space permitted for carrying on the operations of the blast furnace is a disadvantage. The huddling together of the boiling furnaces, so that they may be as near as possible to the fall, operates against the success of this mode of working in close weather. A puddling forge cannot be too open in summer time. Suspension of operations through the exhaustion of the men, produced by the heat evolved by the blast and adjacent boiling furnace, is a common occurrence in these forges, and exists to a greater or less extent in some others.

A species of double furnace, Figs. 4315 to 4317, is now extensively used, with a marked improvement in the yield of coal. A fire-place of large dimensions is provided, and the body is made

4316.

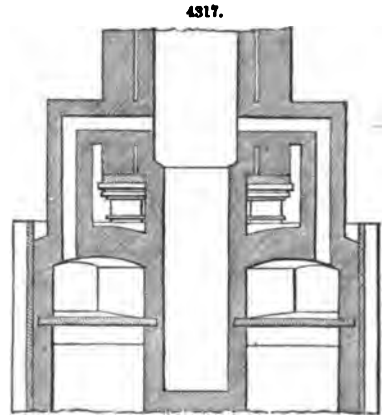


4315.



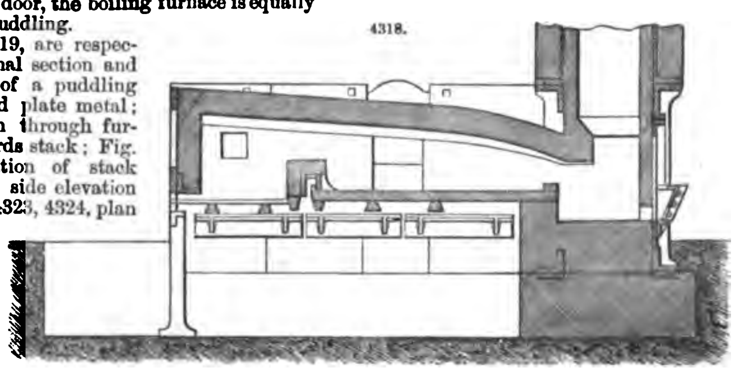
wider than in single furnaces. A working door is made at each side, and two puddlers work at the same time. Twice the usual quantity of pig iron is charged. In all other respects the operation is conducted as in single furnaces. It is difficult, however, to get the puddlers to work well to time. Unless this be done, no advantage is realized over the single furnace. The two men must bring their heats to the respective stages simultaneously, in order to render these furnaces profitable. If one be kept waiting for ever so short a period by the other, the loss in iron more than counterbalances the reduced consumption of coal. This difficulty of obtaining men who will work thus in concert has operated against the general use of double furnaces. Were it not for this circumstance, they would entirely supersede the single furnace. In the double furnace, working hot crude iron, the consumption of fuel is under one-half of the quantity required with single furnaces working cold iron.

4317.



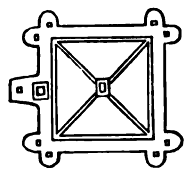
The puddling furnace differs but slightly from the boiling furnace. With a few trifling alterations in the interior, principally confined to lowering the flue-bridge, which in the puddling furnace is seldom more than 6 in. high, and raising the bottom to within 8 in. of the door, the boiling furnace is equally well adapted for puddling.

4318.



Figs. 4318, 4319, are respectively a longitudinal section and a sectional plan of a puddling furnace for refined plate metal; Fig. 4320, section through furnace looking towards stack; Fig. 4321, back elevation of stack frame; Fig. 4322, side elevation of furnace; Figs. 4323, 4324, plan and end views of top of stack showing damper; Fig. 4325, sectional plan of stack; Fig. 4326, section of stack with damper at the bottom; Figs. 4327, 4328, view and section of working door; and Fig. 4329, view of charging door.

4323.



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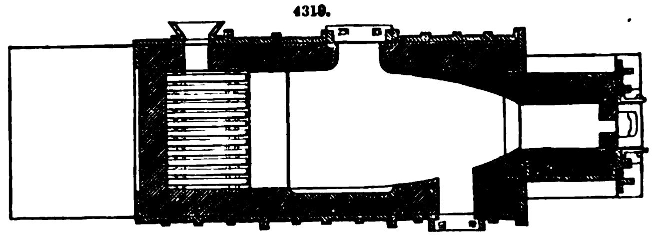

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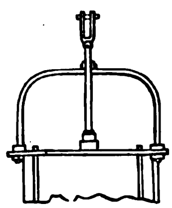

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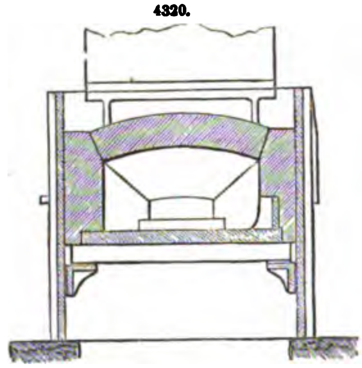

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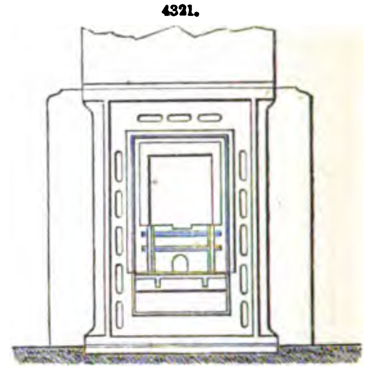

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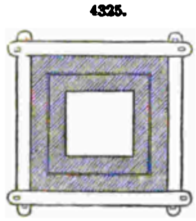

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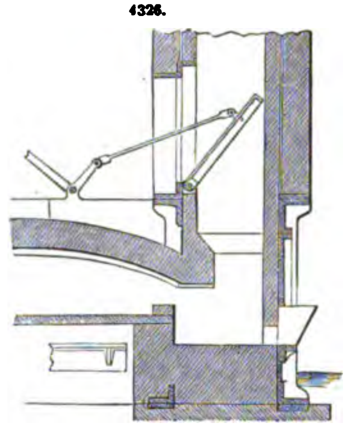

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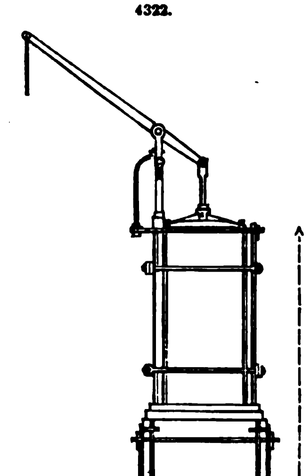
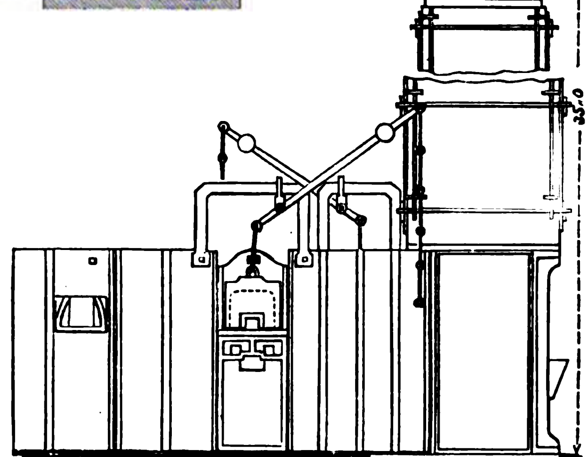

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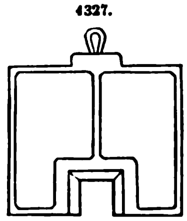

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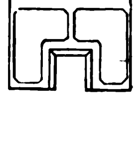


The process differs from boiling in the absence of the swelling and violent agitation of the fluid iron. The general charge is 4¾ cwt. of broken refined metal to a heat. In boiling it is usual to withdraw the finished balls before charging a fresh heat, but in puddling the refined metal is charged through the small door next the flue, at the point when the metal has arrived at the pasty condition. The reduction of temperature consequent on the introduction of a body of cold metal has then no sensible effect in retarding the progress of the operation. The metal is consequently exposed to the furnace flame for a period of fifteen to eighteen minutes before the withdrawal of the heat under operation, and when drawn it is forwarded into the body of the furnace, which has been already elevated to a dull red heat. The damper being opened, a sharp heat is obtained, and in from ten to twelve minutes the metal is melted, and the operation of puddling commences. The same incessant raking motion by the puddler, relieved occasionally by his second hand, is practised as in boiling, and is followed by the separation in a great measure of the iron from the cinder. Finally, it is brought to the same pasty condition, and balled up.

From the time of charging to the extraction of the last ball, the puddling process occupies about one hour and twenty-five minutes: but as the iron is charged fifteen minutes before the extraction of the previous charge, the time actually occupied in working each heat is one hour and ten minutes. With inferior workmen it averages one hour and thirty-six minutes.

The presence of sulphur, and of several metals, including copper, lead, and zinc, retards the puddling process. If any of these are present in considerable quantity, the iron cannot be brought to a pasty condition for balling up, all the efforts of the puddler are thrown away, and the heat eventually has to be raked out. Crude iron rarely contains either of these metals in injurious quantities; but when they obtain admission the pasty character of the mass is destroyed, and the further conversion of cast into malleable iron is totally prevented.

The yield and general quality of several kinds of iron are frequently improved by the addition, during the process of conversion, of a mixture composed of ground magnetic oxide or a rich hematite, caustic lime, and a minimum dose of black oxide of manganese; the quantity added may amount to 5 or 6 per cent. by weight of the charge. The operation is facilitated and the malleablization greatly increased by their employment, which we attribute to the oxygen of the ore and the caustic lime uniting with the carbon and sulphur of the metal.

The time and labour expended in working the superior qualities of iron are greater than that required with the inferior kinds. The grey varieties will require twenty to twenty-five minutes longer in "coming to nature," as the working puddler terms it, the point from which the balling-up process may be said to commence. The cause of this longer time appears to be that the larger quantity of carbon in the metal requires for its evolution longer exposure to the oxygen of the passing current of air, and repeated manipulation to facilitate its escape.

In the working of iron from carbonaceous ironstone the labour is very severe. This metal melting at a low temperature, and containing the largest percentage of carbon, is brought to the malleable state with the greatest difficulty. Its extreme fluidity, the absence of a good cinder for its protection, and the frequent presence of sulphur, lengthen the process, add to the waste, and reduce the quality.

Puddling hot iron direct from the refinery has also been practised, but it is doubtful if the advantages from this mode of working can ever be such as to cause its extensive adoption. The crude iron, after being refined, is run into a puddling furnace and worked in the usual manner. The invention is a very old one, having been first tried nearly half a century ago. A due separation of the metal from the cinder of the finery appears to be the principal difficulty in this mode of working. In the ordinary finery the metal and cinder escape together from the hearth, but by this plan the metal only is allowed to enter the puddling furnace, the cinder being obtained in a separate running. Close attention is required to be paid to the separation; if cinder enters the furnace along with the metal, the conversion into malleable iron is rendered more difficult, while the escape of metal along with the cinder results in a direct loss.

Puddling with steam has been several times experimentally essayed, but after an extensive trial it was discovered that the advantages were not commensurate with the expense of applying and maintaining the apparatus.

In the early puddling furnaces the body between the ash-pit and the stack was filled up nearly to the level of the intended bottom with cinder or other material; above this a sand bottom was made on which the puddling was conducted. The sand bottom, however, gave way to the iron bottom, now universally adopted in preference to any other. For boldness and originality the idea of using a thin plate of cast iron as a bottom for a furnace constructed expressly for melting crude iron has not been equalled, but without it the puddling process could not have attained its present high state of perfection. Next to the invention of puddling, the iron bottom was the greatest improvement effected in the operation of converting cast into malleable iron bars.

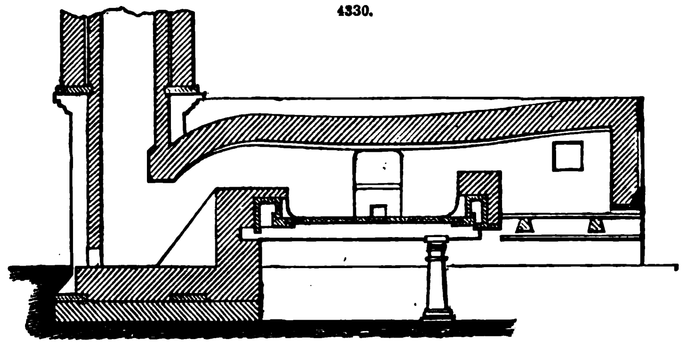
While sand bottoms were used the yield was extravagantly high, the consumption of coal in the furnace was great, and the resulting bar iron, through mingling with a portion of the silicious bottom, was inferior in quality. This inferiority would have been more apparent but for the employment of the ponderous forge hammers of that period. A portion of the cinder was expelled during the violent hammering to which the blooms were subjected; but as a quantity of the metal was also detached the improvement was not effected without great waste of iron. Formerly the ton of puddled bars was made with a consumption of 30 cwt. and sometimes as much as 36 cwt. of refined metal. At present it is done with about 21 cwt.

The portions of the furnace exposed to the intense heat, and the action of the fluid metal, unprotected by cinder, are rapidly burnt away. For repairing, fire-clay is largely used in several works, while in others calcined forge cinders are successfully employed. Cinder, when the calcination has been carried so far as to convert it into a refractory silicate of iron, is undoubtedly the best material. It does not appear, however, from experiments, that all forge cinders are equally applicable to this purpose. Such as contain a large quantity of metal, and a sparing quantity of silica,

cannot be used with the same success as leaner cinders. Limestone is frequently used in boiling furnaces by the puddler in preference to any other material.

The consumption of iron to produce one ton of puddle-bars by the boiling process varies with the quality of the pigs, and to some extent with the quality of the coal. The yield of good forge pigs smelted from a high burden we find to average 21 cwt. 3 qrs. with a forge of puddlers of average ability; with less able men in other forges, working under precisely similar conditions, the yield has been 22 cwt. 3 qrs. 14 lbs. If the conditions are very favourable and the puddler skilful, the ton of puddle-bars can be produced from 21 cwt. 1 qr. of pigs.

4330.



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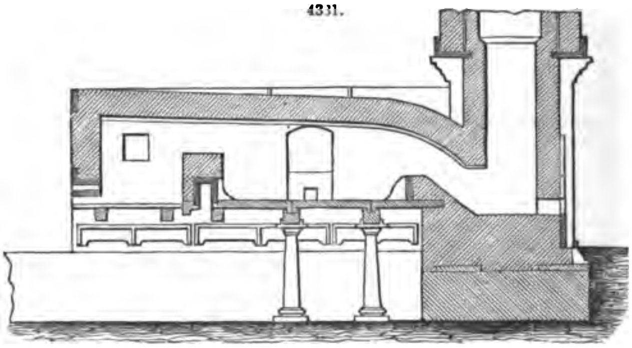
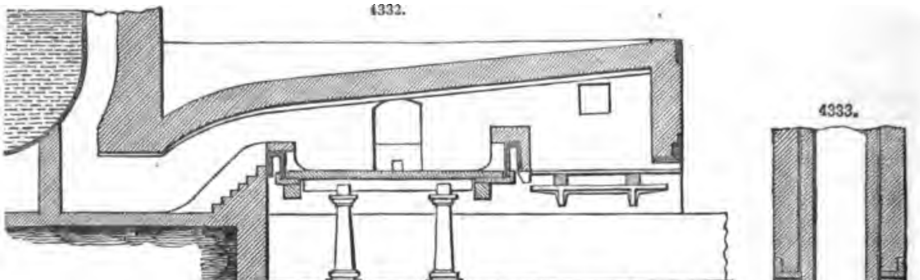


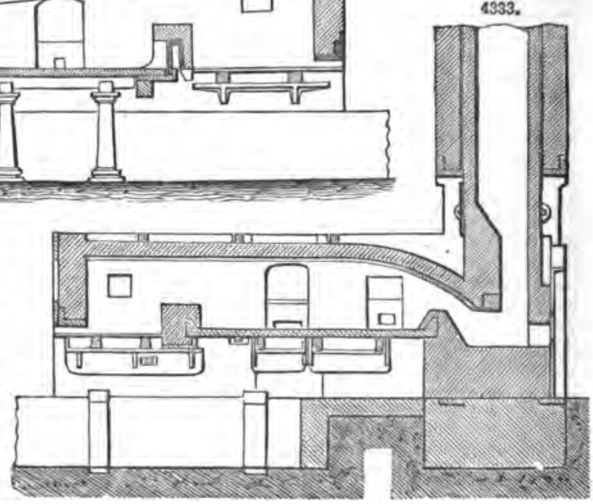
The yield of the iron from carbonaceous ore is probably worse than that from any other description. From the working of the large forges at the Monkland and Dandyvan works, it has been found that the consumption of pigs in these establishments in the boiling process averages 23 cwt. 3 qrs. 19 lbs. a ton of puddle-bars.

The ton of puddle-bars may be produced by the puddling process with a consumption of

4332.



4333.



21 cwt. 1 qr. of refined metal. This is the average consumption in a forge of sixteen furnaces worked by men of fair average ability. All circumstances being favourable, a ton can be produced with 20 cwt. 3 qrs. of metal. But taking the average of eighty-five furnaces over twenty-two years, we find the yield to average 21 cwt. 1 qr. 20 lbs.

The consumption of coal is subject to similar variation with a bituminous coal yielding much flame; the consumption with superior workmen will average 14 cwt. a ton of boiled iron bars. With a less inflammable coal it will rise to 18 cwt., and with the coals mined on the edge of the anthracite basin 22 cwt. is near the average. The weekly consumption of cole at the furnace is nearly the same, whatever varieties of iron may be under operation, so that with the kinds most difficult of conversion the yield a ton is increased in the same ratio as the make is reduced. Inferior puddlers will burn 4 to 5 cwt. a ton more than able men. The double boiling furnace effects a considerable saving of fuel if successfully managed. The yield of coal is nearly one-fourth less than with single furnaces.

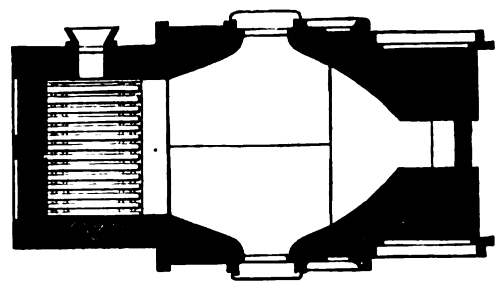
The consumption of fuel in puddling refined metal is smaller than with pigs. With coal of good quality and suitable for the purpose the ton of puddle-bars is produced with a consumption of 10 cwt. only; proceeding, however, to the semi-anthracite coal district, the consumption rises to 17 and 18 cwt. a ton.

A more perfect combustion of the coal, resulting in a slight reduction in the quantity used, has been produced by introducing into the fire-place above the fuel atmospheric air for burning the gaseous products. This invention requires closed ash-pits for its successful application; the air supplied to the coal above and below the bars is heated in flues underneath and at the sides of the furnace. The mixing of the gases and air is effected by a perforated divisional bridge through which the heat passes to the body of the furnace. Irons melting at a low temperature have been worked with a considerable saving of fuel, but with the harder kinds the obstructions caused to the draught by the bridge renders the furnace less manageable, and the loss in the yield of iron is of far greater value than any saving of coal.

Figs. 4330 to 4332 are longitudinal sections of puddling furnaces with iron boshes, Fig. 4332 being an arrangement with boiler in flue; Figs. 4333, 4334, sections and plan of a furnace in the

4334.

4335.



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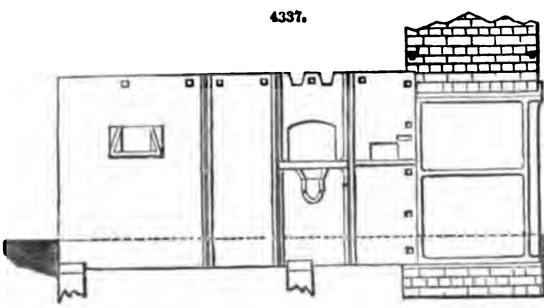

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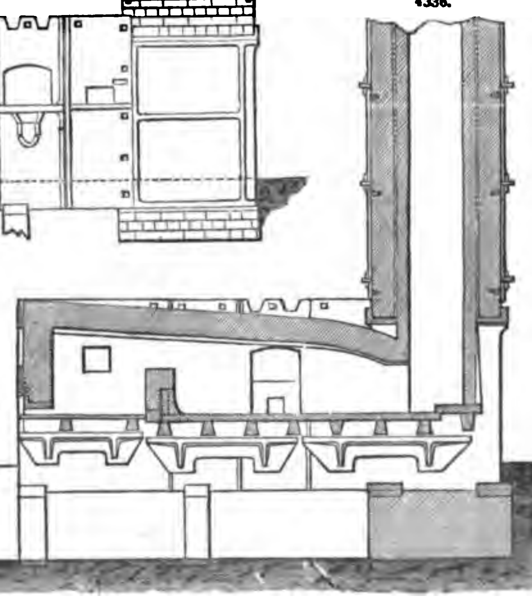
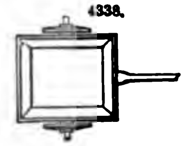


4338.



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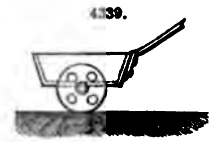
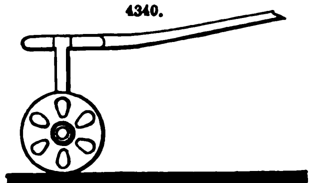


4342.

4340.



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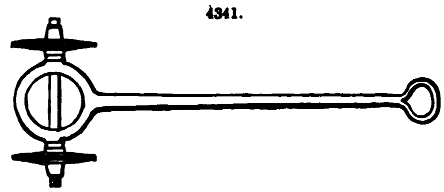
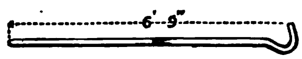


Cyfarthfa Iron-works; Figs. 4335 to 4337, plan, section, and side elevation of a common double puddling furnace; Figs. 4338, 4339, tub for cinder; Figs. 4340, 4341, carriage for conveying

puddling balls to squeezer or shingling hammer; Figs. 4342 to 4346, puddlers' tools; and Figs. 4347, 4348, section and plan of part of puddling forge—Dowlais Iron-works—showing arrangement of furnaces, coal and iron tramways, races, and so on.

The horizontal area of the chimney-flue at the junction of the stack with the puddling furnace

4343.



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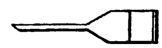

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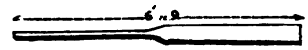
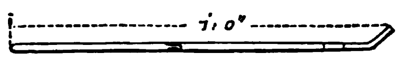
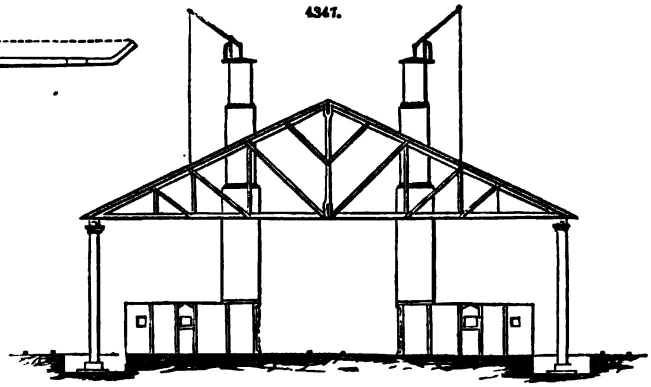


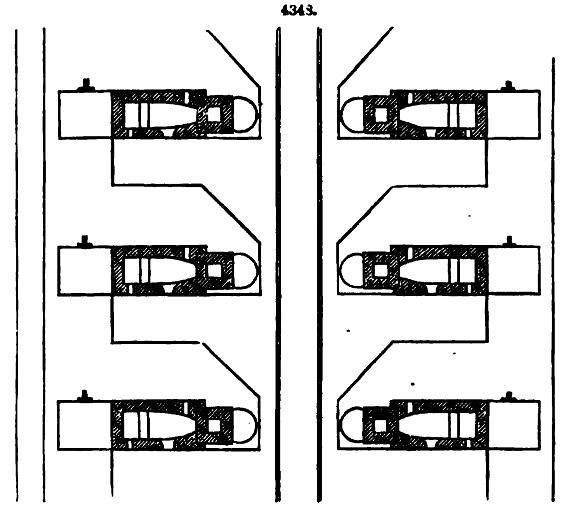
4345.



4347.



4348.



is mainly dependent on the character of the coal. With the highly bituminous varieties, which swell considerably during their combustion, and by lying close in the grate cause an obstruction to the draught, the flue in this place—or, as it is termed by builders, the take-up—is made about 18 in. square; the grate measuring 2 ft. 8 in. by 3 ft. 9 in. This is at the rate of 32 in. of flue to each superficial foot of grate. At the Hirwain Works, where the coal is of a semi-anthracite nature, producing little flame, and increasing very slightly in bulk during combustion, the take-up is 17 in. by 10 in. for grates 2 ft. 4 in. by 3 ft. 5 in.; equal to 21 in. to each foot of grate.

The area of the take-up is regulated also by the skill of the puddler. A good workman will prefer it contracted, but an inferior hand desires an increased area. To a workman less skilful in the manipulation of the iron, the enlarged area affords greater control over the draught, but at the expense of the iron under operation, a portion of which is thus oxidized and lost. The maintaining of the take-up unaltered is considered of the first importance with puddlers, and where it is constructed with fire-brick its enlargement after a week's work requires that it should be taken down and renewed. Sandstone, from its greater durability, has been adopted at some works. If the take-up be not reconstructed of the original size, the yield of metal becomes worse as the area is enlarged. Hence, with a forge of good workmen, we find that as the time approaches for repairing the yield of iron a ton is augmented.

The area of the grate is dependent, in a great measure, on the quality of the coals. At the Hirwain forges an area of 8 ft. is adopted as sufficient with their coal; but at the other forge belonging to the same works, and working iron from the same blast furnaces, we find the grates averaging 10 ft. in area. From the very different qualities of the coals, however, the lesser area of grate at Hirwain burns a greater quantity than the large grates at the Forest Works, although the area of the take-up in the latter furnace is nearly twice that in the former.

The make of a boiling or a puddling furnace is dependent on the skill of the puddler, the quality of iron operated on, and the general character of the coal. Where these are favourable the weekly make will not fall short of 21 tons, and the average may be estimated at 18 tons. This, however, is greatly above the production in some districts. The Staffordshire furnaces, for instance, do not usually average more than 10 tons weekly.

The lesser make of the Staffordshire furnaces may be explained by the shorter time they are at work, and the slower rate of working practised by the puddlers. In the Welsh district, with an abundant supply of the raw materials, iron and coal, the furnace is under work one hundred and forty hours weekly, the only stoppage being four hours on Saturday evening and the whole of Sunday. In Staffordshire the furnaces are lit on Monday evening and let out early on Saturday,

the working period seldom exceeding one hundred and four hours weekly. From keeping the furnaces longer at work each week the Welsh ironmasters are enabled to turn out a comparatively large quantity of iron with a limited number of furnaces. The yield of metal is believed to be improved, while there can be no question but that the yield of coal is considerably diminished. A certain quantity is expended every week in getting up the heat. The consumption in this way for each ton of iron will be in an inverse ratio to the weekly make.

The make of the double boiling furnace averages 36 tons weekly. Working on hot iron from the blast furnace the make is as high as 46 tons weekly. Similar furnaces at the Chillington forges, Staffordshire, produced about 28 tons weekly.

The make of puddling furnaces, working on all refined metal, depends very much on the skill of the puddler. With first-rate workmen, and iron and coal favourable, the produce will reach 28 tons; with inferior hands the make will be about 21 tons. Taking an average of eighteen years' puddling, Truran found that the make of puddle-bars from five forges was 23 tons a week for each furnace at work.

Puddling with wood is practised to a considerable extent in Sweden, the best furnace being that of F. Lundin, of Carlstadt Munkfors, Fig. 4349, designed for the consumption of turf and peat without drying, and of wet saw-dust or other moist fuel. A, Fig. 4349, is a pile of green saw-dust; B, hopper and cone; D, gas generator for green saw-dust; G, condenser; H, heating furnace with Siemens' regenerator: I I, valve-box; K, air-blast; N, regenerator for gas; P, regenerator for air; S, chimney, 43 ft. high; T, blast throttle-valve; X X, dampers to regulate issuing gas; Y Y, 3500 lbs. of iron in bars, cooled by the water from pipe Y Y, to cool the gas and precipitate the water; L, 45 per cent. of water; Z, water at 2°; at *e* the temperature is 20°, where it rises to 300°; at *s*, 300°; at *d*, 350°; at C, 400° to 420° C.

The temperature used to burn the gas, calculated from the cold air, is about 2000° C.

At R, lead melts slowly; at F, lead melts easily; at E, zinc sometimes melts; M, melting-point of cast iron.

V is the plan of the auxiliary furnace for first heating; W, the plan of the reheating furnace. The gas, before condensation, contains 33 parts by weight of water to 100 of dry gas.

Constituents of Gas.

11·8 vol.	acid carbonic	19·6 weight.
19·8 „	oxide „	20·8 „
11·3 „	hydrogen	0·87 „
4·0 „	marsh gas	2·4 „
53·1 „	nitrogen	56·3 „

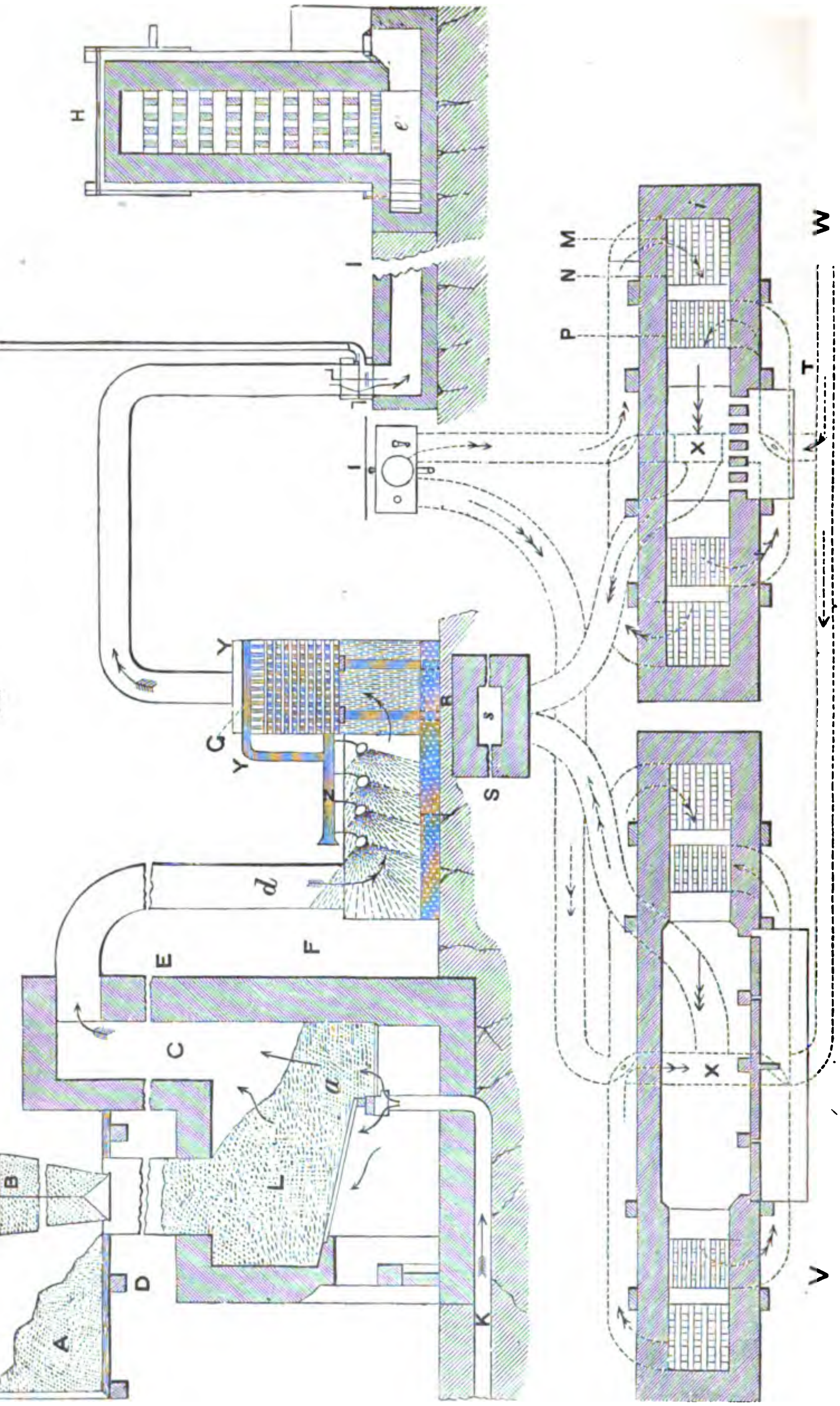
Same before as after condensation.

The furnace may be placed at a long distance from the condenser.

In this furnace the fuel is fed by a hopper into a reservoir, resting upon an inclined grate, supplied from below with air from a blower. The products of combustion thus produced pass through a condenser, where all the moisture in the gas is condensed. The gas then passes to the heating furnace, which is furnished with Siemens' regenerators. It is found easy to use fuel containing as much as 45 per cent. of water, the resulting gas contains about 33 lbs. of water to 100 lbs. of dry gas, and the water, after condensation, contains about 2 per cent. of its weight in gas, or 3 per cent. of its volume. The condensing apparatus consists of 3500 lbs. of iron bars piled crosswise on each other, and kept cold by a jet of water from a tuyere. The heat of the gas before condensation of the water always melts lead easily, and sometimes zinc. In the Ekman furnace dry wood containing 8 per cent. of water produces in the generators gas of a temperature of 1394°, while in the Lundin furnace the temperature is 2066°, the combustion in both cases being produced by cold air. The gas produced by seasoned wood contains more water than that which proceeds from the Lundin condenser. The duration of the furnace is very remarkable, and is to be attributed probably to the fact that there is no cinder. In eight weeks the thickness of the roof, 4 in., was only diminished from ¼ to ⅜ in., and the side walls were entirely uninjured. So great is the success of this system of condensation, in connection with the Siemens' regenerators, that in Sweden, and in fact everywhere where moist fuel is employed, the Lundin furnace will supersede every other. Abram S. Hewitt considers that it is available for any kind of fuel whatever. In the United States it is believed that this arrangement might be employed advantageously for washing the gas obtained from mineral coal; but its chief merit consists in the fact that in mineral regions, far removed from coal-fields, it is possible to establish iron-works, using saw-dust or peat with success and economy. In the lumber regions of Lake Superior, says Hewitt, it will be found to have a special value, because there is an abundant supply of pig accessible to the saw-mills on Green Bay and in Michigan, producing enormous quantities of saw-dust, slabs, and waste timber

Siemens' Gas Puddling Furnace.—The fuel employed in this furnace, which may be of an inferior description, is separately converted into a crude gas, which, in being conducted to the furnace, has its naturally low heating power greatly increased by being heated to nearly the high temperature of the furnace itself, ranging to above 3000° Fahr.; undergoing at the same time certain chemical changes whereby the heat developed in its subsequent combustion is increased. The heating effect produced is still further augmented by the air necessary for combustion being also heated separately to the same high degree of temperature, before mixing with the heated gas in the combustion-chamber or furnace; and the latter is thus filled with a pure and gentle flame of equal intensity throughout the whole chamber. The heat imparted to the gas and air before mixing is obtained from the products of combustion, which after leaving the furnace are reduced to a temperature frequently not exceeding 250° Fahr. on reaching the chimney; thus great economy in fuel is produced, with other advantages.

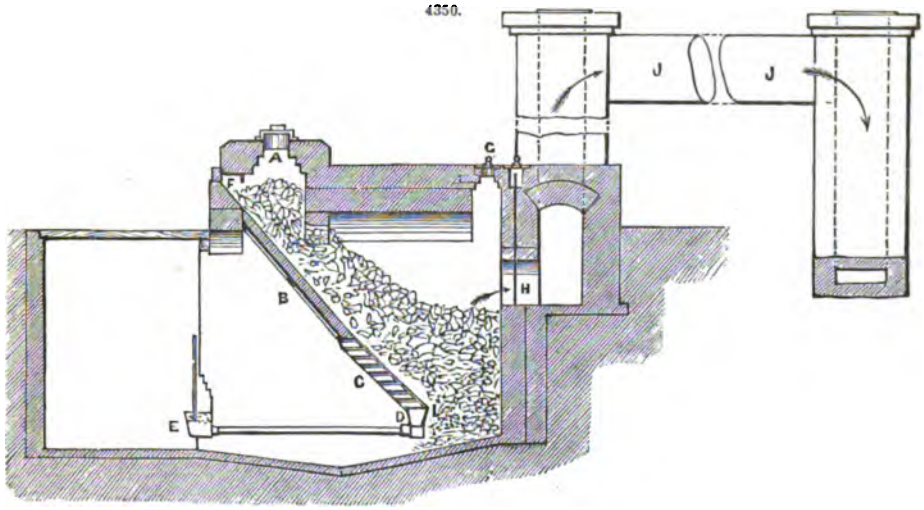
4319.



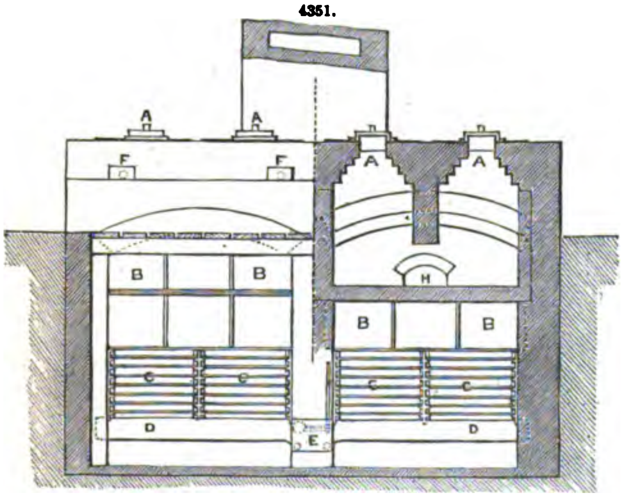
The transfer of heat from the products of combustion to the air and gas entering the furnace is effected by means of regenerators, or as Percy terms them, Accumulators.

The gas producer is shown in Figs. 4350 to 4352. Fig. 4350 is a longitudinal section, Fig. 4351 a front elevation and transverse section at the front, and Fig. 4352 a transverse section at the back.

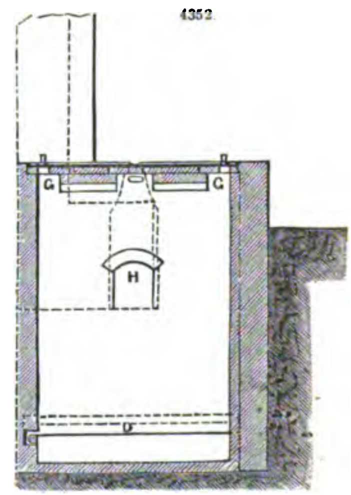
4350.



4351.



4352.



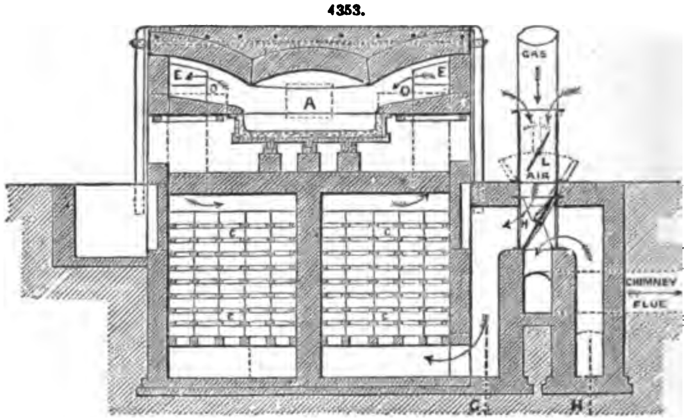
The producers are entirely separate from the furnace, where the heat is required, and are made sufficient in number and capacity to supply several furnaces. The fuel, which may be of the poorest description, such as slack, coke-dust, lignite, or peat, is supplied at intervals of from six to eight hours through the covered holes A, Figs. 4350, 4351, and descends gradually on the inclined plane B, which is set at an inclination of from 45° to 60° according to the nature of the fuel used. The upper portion of the incline B is made solid, being formed of iron plates covered with fire-brick; but the lower portion C is an open grate formed of horizontal flat steps. At the foot of the grate C is a covered water-trough D, filled with water up to a constant level from the small feeding cistern E, supplied by a water-pipe with a ball tap. The large opening under the water-trough is convenient for drawing out clinkers, which generally collect at that point. The small stoppered holes F F at the front and G G at the top of the producer are provided to allow of putting in an iron bar occasionally to break up the mass of fuel and detach clinkers from the side walls. Each producer is made large enough to hold about 10 tons of fuel in a low incandescent state, and is capable of converting about 2 tons of it daily into a combustible gas, which passes off through the opening H into the main gas-flue leading to the furnaces.

The action of the gas producer in working is as follows; the fuel descending slowly on the solid portion B of the inclined plane, Fig. 4350, becomes heated and parts with its volatile constituents, the hydro-carbon gases, water, ammonia, and some carbonic acid, which are the same as would be evolved from it in a gas retort. There now remains from 60 to 70 per cent. of purely carbonaceous matter to be disposed of, which is accomplished by the slow current of air entering through

the grate C, producing regular combustion immediately upon the grate; but the carbonic acid thereby produced, having to pass slowly on through a layer of incandescent fuel from 3 to 4 ft. thick, takes up another equivalent of carbon, and the carbonic oxide thus formed passes off with the other combustible gases to the furnace. For every cubic foot of combustible carbonic oxide thus produced, taking the atmosphere to consist of one-fifth part by volume of oxygen and four-fifths of nitrogen, 2 cub. ft. of incombustible nitrogen pass also through the grate, tending greatly to diminish the richness or heating power of the gas. Not all the carbonaceous portion of the fuel is, however, volatilized on such disadvantageous terms; for the water-trough D at the foot of the grate, absorbing the spare heat from the fire, emits steam through the small holes I under the lid; and each cubic foot of steam in traversing the layer of from 3 to 4 ft. of incandescent fuel is decomposed into a mixture consisting of 1 cub. ft. of hydrogen and nearly an equal volume of carbonic oxide, with a variable small proportion of carbonic acid. Thus 1 cub. ft. of steam yields as much inflammable gas as 5 cub. ft. of atmospheric air; but the one operation is dependent upon the other, inasmuch as the passage of air through the fire is attended with the generation of heat, whereas the production of the water gases, as well as the evolution of the hydro-carbons, is carried on at the expense of heat. The generation of steam in the water-trough being dependent on the amount of heat in the fire, regulates itself naturally to the requirements; and the total production of combustible gases varies with the admission of air. And since the admission of air into the grate depends in its turn upon the withdrawal of the gases evolved in the producer, the production of the gases is entirely regulated by the demand for them. The production of gas may even be arrested entirely for twelve hours without deranging the producer, which will begin work again as soon as the gas-valve of the furnace is reopened; since the mass of fuel and brickwork retain sufficient heat to keep up a dull red heat in the producer during that interval. The gas is, however, of a more uniform quality when there is a continuous demand for it, and for this reason it is best to supply several furnaces from one set of producers, so as to keep the producers constantly at work. The opening H leading from each producer into the main gas-flue can be closed by inserting a damper from above, as shown in Fig. 4350, in case any one of the producers is required to be stopped for repairs, or because part of the furnaces supplied are out of work.

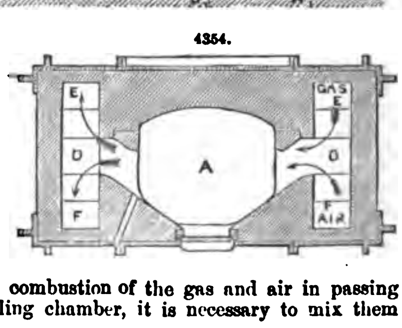
It is important that the main gas-flue leading to the furnaces should contain an excess of pressure, however slight, above the atmosphere, in order to prevent any inward draughts of air through crevices, which would produce a partial combustion of the gas, and diminish its heating power in the furnace, besides causing a deposit of soot in the flues. It is therefore necessary to deliver the gas into the furnace without depending upon a chimney draught for that purpose. This could easily be accomplished if the gas producers were placed at a lower level than the furnaces, but as that is generally impossible, the following plan has been adopted. The mixture of gases on leaving the producers has a temperature ranging between 300° and 400° Fahr., which must under all circumstances be sacrificed, since it makes no difference to the result at what temperature the gas to be heated enters the regenerators, the final temperature being in all cases very nearly that of the heated chamber of the furnace, or say 2500° Fahr. The initial heat of the gas is therefore made available for producing a plenum of pressure by making the gas rise about 20 ft. above the producers, then carrying it horizontally 20 or 30 ft. through the wrought-iron tube J, Fig. 4350, and letting it again descend to the furnace, as shown by the arrows. The horizontal tube J being exposed to the atmosphere causes the gas to lose from 100° to 150° of temperature, which increases its density from 15 to 20 per cent., and gives a preponderating weight to that extent to the descending column urging it forward into the furnace.

4353.



Figs. 4353 to 4358 represent a puddling furnace constructed on C. W. Siemens' plan. Fig. 4353 is a longitudinal section of the furnace; Fig. 4354 a sectional plan of the puddling chamber; Fig. 4355 a sectional plan of the regenerators; Fig. 4356 is a transverse section at the end of the furnace; and Figs. 4357, 4358, are vertical sections through the gas and air passages.

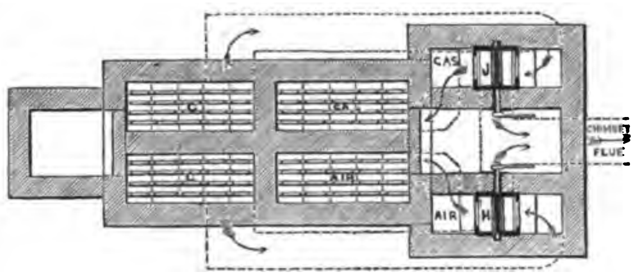
4354.



The four regenerators C are arranged longitudinally underneath the puddling chamber A, which may be of the usual form. In order to complete the combustion of the gas and air in passing through the comparatively short length of the puddling chamber, it is necessary to mix them

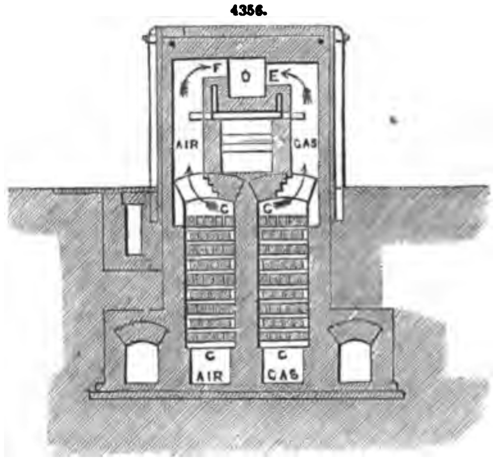
intimately. For this purpose a mixing chamber O, Fig. 4353, is provided at each end of the puddling chamber, and the gas and air from the regenerators are made to enter the mixing chamber from opposite sides, as shown in Fig. 4356; the gas aperture E is placed several inches lower than the air aperture F, so that the lighter stream of gas rises through the stream of air while both are urged forward into the puddling chamber, and an intense combustion is produced. The mixing chambers O are sloped towards the furnace, as shown in Fig. 4353, in order to drain them of any cinders which may get over the bridge. The reversal of the current through the furnace is effected about every hour by the reversing valves H and J in the air and gas flues, the arrangement of which is exactly similar to that in Siemens' glass furnace; the supply of gas and air is regulated by the throttle-valves L, and the draught through the furnace by the ordinary chimney damper.

4355.



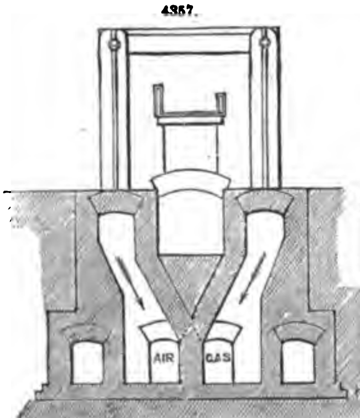
This same arrangement, with obvious modifications, may be applied also to blooming and heating furnaces, the advantages in both cases being a decided saving of iron, besides an important saving in the quantity and quality of the fuel employed. The space saved near the hammer and rolls by doing away with fire-places, separate chimney-stacks, and stores of fuel, is also a considerable advantage in favour of the regenerative gas furnace in iron-works. The facility which it affords for either concentrating the heating effect or diffusing it equally over a long chamber, by effecting a more or less rapid mixture of the air and gas, renders the furnace particularly applicable for heating large and irregular forgings or long strips or tubes which have to be brought to a welding heat throughout.

4356.



Many attempts have been made to apply machinery to the purpose of puddling iron, and relieving the puddler from the heaviest portion of his laborious work, but they have not been received with much favour, the most promising being an arrangement to rotate the rabble by means of a belt and pulley. Other attempts have been made to dispense with manual labour altogether in puddling by giving motion to the furnace itself, in order to produce the necessary agitation in the metal, and so render the use of tools nearly or altogether unnecessary. The plan that has been most successful is the invention of an American, Samuel Danks.

4357.



4358.

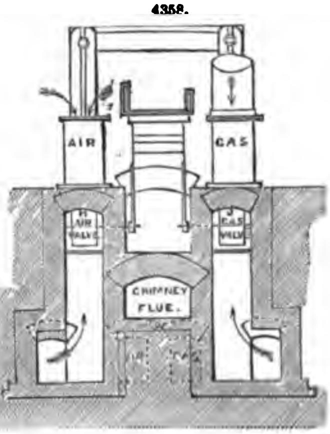
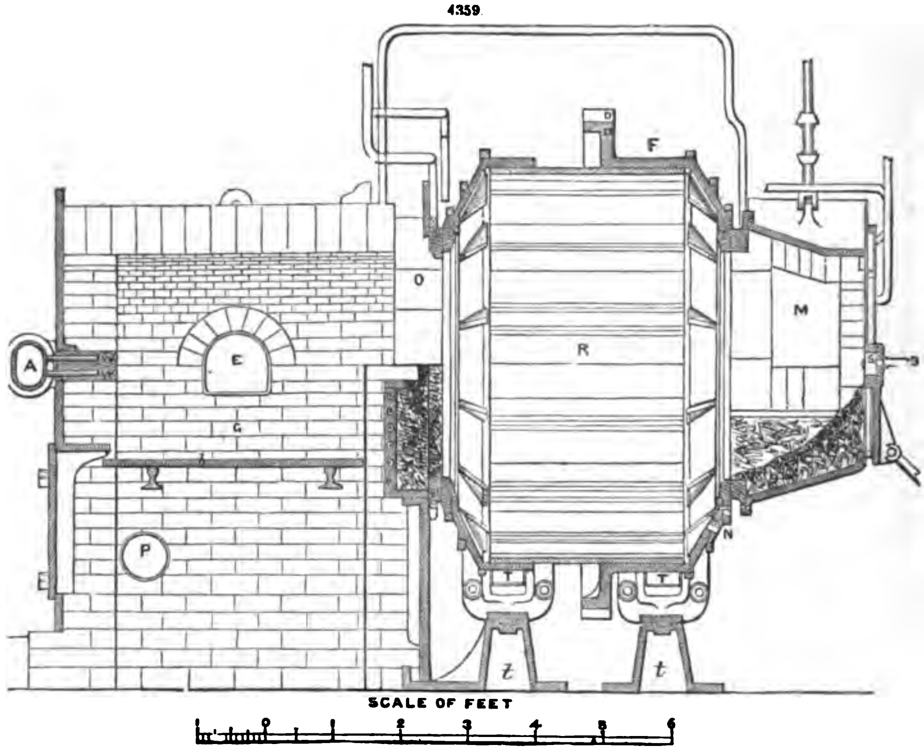


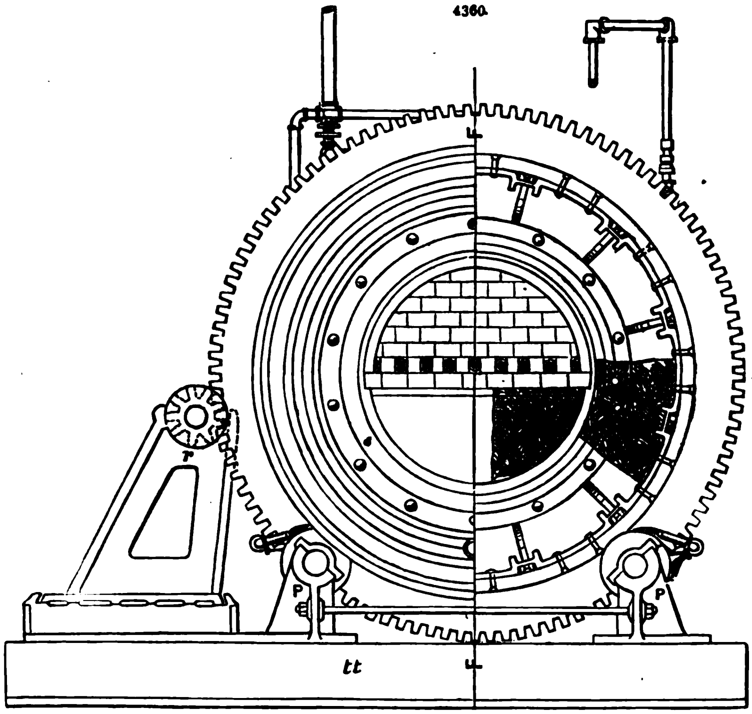
Fig. 4359 is a sectional elevation; Fig. 4360 a cross-section of revolving chamber; Fig. 4361 a horizontal section of revolving chamber; Fig. 4362 an elevation of movable end-piece and flue; Fig. 4363 a front sectional elevation of squeezer; and Fig. 4364 an end elevation of squeezer, of Danks' rotary puddling machine. R is the revolving chamber; M, movable piece; O, passage for gases; T, carrying rollers; N, tapping hole; S, stopper-hole, E, fire-hole; P, wind-pipe; W W, wind-jet pipes; *t*, bed-plate; *o o*, gear-wheels; *g*, fire-grate; *b*, grate-bar; *r*, standard; *p*, wind-valve; G G, grate-bars; 1, chimney-stack; 2, stationary flue; 3, bridge-ring; 4, fire-bridge; 5, suspension-rods, with swivels; 6 6, water-pipes; 7, water front

of movable piece; C C, Figs. 4363, 4364, bed-plates; D, squeezer-roll; C, squeezer-cam; F F, housing; G G, gear-wheels; B, steam-ram; A, steam-cylinder; b, head of steam-ram; D D, roll.

4359.



4360.



The furnace has a fire-grate, in outward appearance like the ordinary puddling furnace, but it differs from this considerably in several particulars. It has a fan blast under the grate, to urge the fire and produce gas. It has also jets of fan blast *over* the fire, injected for the purpose of ensuring the more perfect combustion of the fuel. This blast is regulated by a valve, by which the workman has a perfect control of the quantity of gas produced and consumed, and he is thus enabled to make the temperature suit the requirements of the charge in the different stages of the puddling process. The ash-pit and fire-hole are closed by doors, to prevent the escape of the blast through the fire, and the fire-hole has a coil of wrought-iron water-pipe cast into it, for the purpose of allowing a stream of water to circulate around it to keep it cool. The bridge-plate between the fire and the charge of metal has also a coil of water-pipe cast into it for the same purpose. It has

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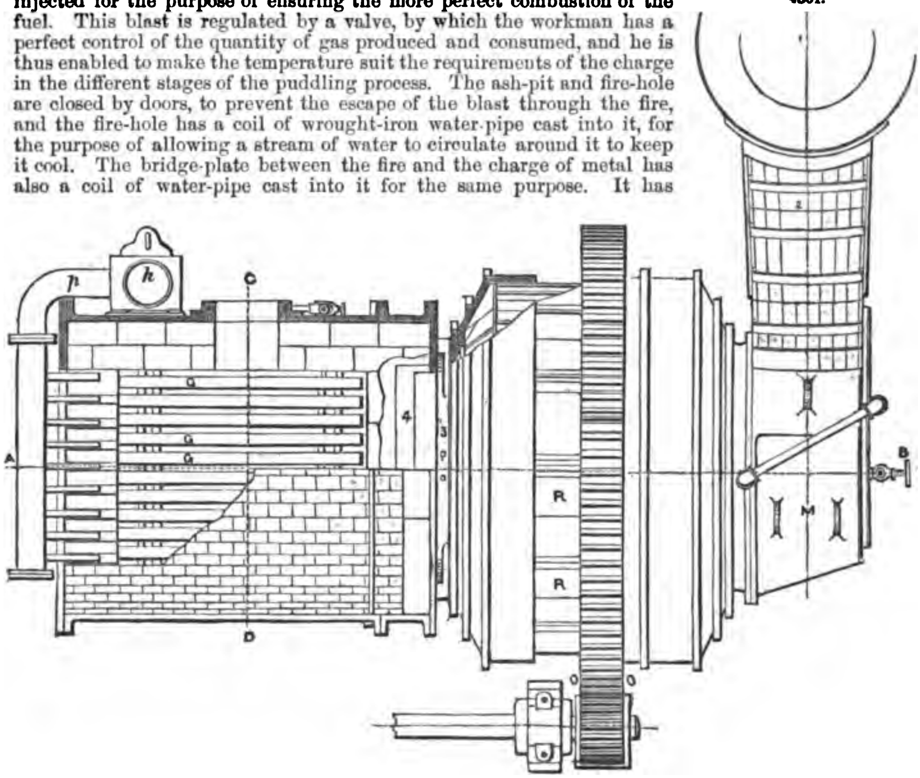

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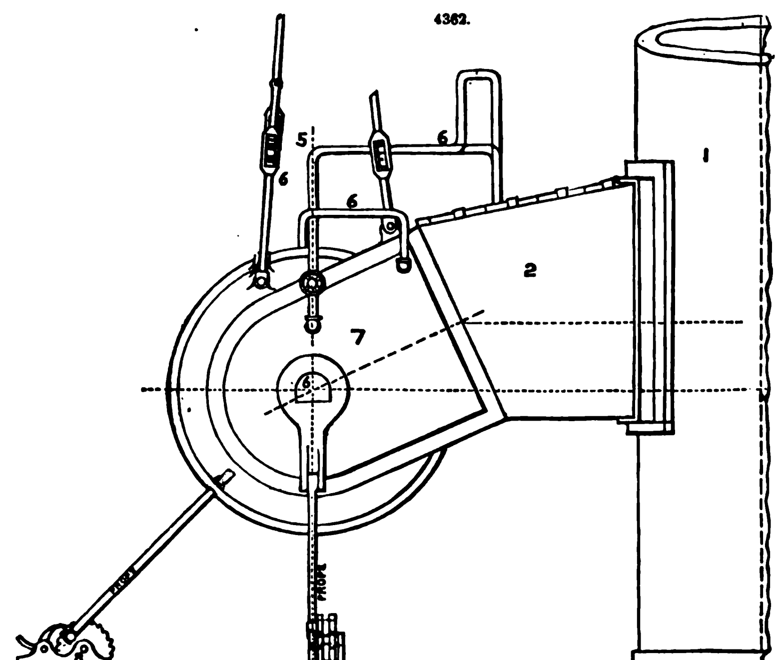
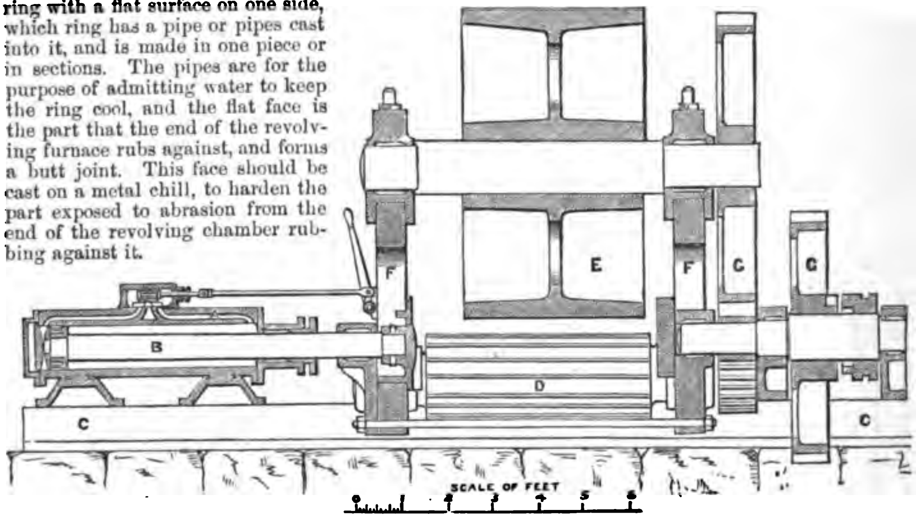


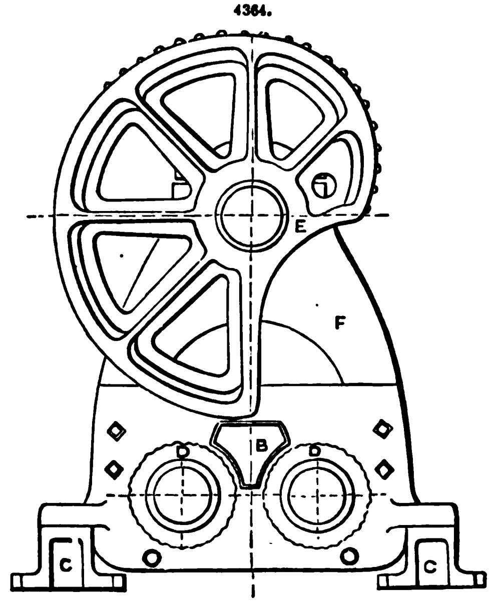
a lining of fire-brick on the side next to the fire, and a covering of fettling on the side next to the charge. It also has a course of fire-brick on the top, and is thus perfectly protected on all sides. Fastened on to the bridge-plate is a ring with a flat surface on one side, which ring has a pipe or pipes cast into it, and is made in one piece or in sections. The pipes are for the purpose of admitting water to keep the ring cool, and the flat face is the part that the end of the revolving furnace rubs against, and forms a butt joint. This face should be cast on a metal chill, to harden the part exposed to abrasion from the end of the revolving chamber rubbing against it.

4363.



The revolving chamber is made of two end-pieces, so formed as to be banded with wrought-iron bands, and to have detachable rings on the part most exposed to the fire. It rests on carrying rollers, to allow its free rotation. It has also suitable ribs for strengthening it, and holes for riveting the rings and stave-plates upon it. These two ends are connected together by a series of stave-plates to form a cylinder, and are of suitable length according to the desired size of the chamber. They have hollow ribs, running longitudinally, which serve the double purposes of holding the fettling and keeping it cool, and when riveted together, form an open-ended cylinder, one end of which butts against the ring that is fastened to the bridge-plate, where the gases are admitted over the bridge from the grate, and the other open end serves the purpose of a doorway for the reception of the charges of metal, and for their removal; also for the escape of the products of combustion through a movable head-piece which connects the revolving chamber and the chimney. This movable piece answers the purposes both of door and flue. It can be moved at pleasure by means of a suitable apparatus overhead, and when in its place for puddling, the escaping gases pass through it into the stationary flue, and from thence to the chimney or boiler. When it is removed for the introduction or removal of the charge, the end of the revolving chamber is open, and balls of great weight can be very readily removed. When the movable piece is adjusted for puddling, it is held in position by suitable props. It has also an arrangement of water-pipes for keeping it cool, and a stopper-hole in front, so that the operations going on inside can be seen at all times.

4364.



The vessel is made to revolve by means of a toothed wheel, fixed longitudinally upon it. A suitable engine is attached to each machine, so that the chamber can be made to revolve at any speed that may be required according to the different stages of the operation.

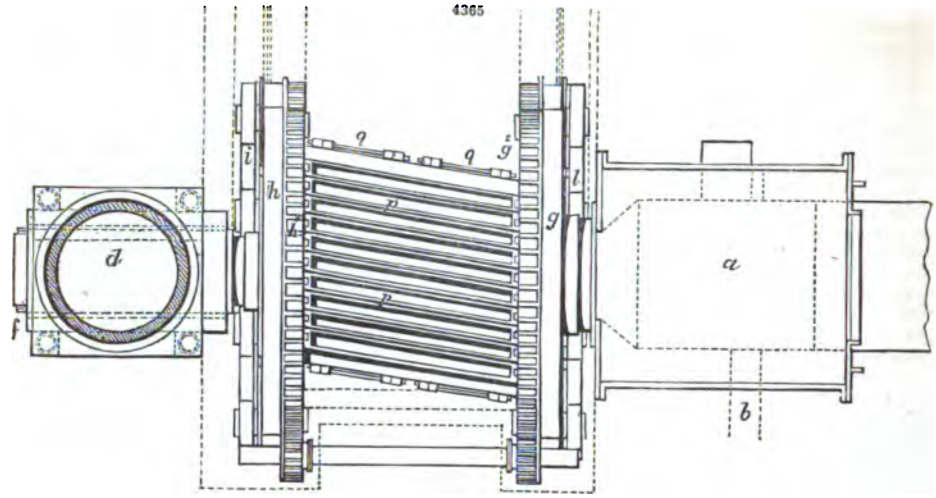
The chamber is lined in the following manner;—The initial lining is composed of a mixture of pulverized iron ore and pure lime, worked with water into the consistency of a thick paste. About one-third of the inner surface of the chamber is covered with this mortar in a layer projecting about 1 in. over the hollow ribs. After about four hours the first part of the lining, as described, will be found hard, and in the same way the remaining parts are filled in and are allowed to set. The furnace is then ready to receive the fettling. About one-fifth of the whole quantity required in the shape of pulverized iron ore is thrown in upon the above-mentioned lining. The furnace is

heated up, and is made to revolve slowly until the iron ore is found to be completely melted. The apparatus is then stopped, and that part of the molten iron ore, which has not been consumed by glazing the initial lining surface, runs to the lowest level of the furnace, and there forms a pool, into which there are put a number of small and large lumps of iron ore, of such dimensions as will be required to allow the said lumps to project over the surface of the liquid ore by from 2 to 6 in. This first part of the fettling is allowed to set, when a fresh quantity of pulverized ore is thrown in. The furnace is again made to rotate slightly until the newly-added ore is liquefied, when the apparatus is again stopped, and the pool is filled with lumps as before. In this manner the whole of the inner surface is gradually fettled, and care is taken to regulate the position of each pool, so that the vessel or apparatus shall at all times find itself properly balanced. From 2 to 2½ tons of iron ore are required to fettle a 700-lb. rotary furnace. Rather more than the ordinary quantity of hammer or rolled cinder is used, and upon that the iron is charged either in a solid or molten condition. When charged in the shape of pig iron, the melting down occupies from thirty to thirty-five minutes, during which a partial rotation is given to the furnace from time to time, in order to expose equally all sides of the charge to the flame. When the whole of the charge is thoroughly melted, the furnace is made to revolve once or twice a minute only during the first five or ten minutes. in order to obtain the most perfect action of the cinder upon the molten iron. A stream of water is injected through the stopper-hole along and just above the line of contact between the floating cinder and the inner surface of the vessel on the descending side. A certain portion of uncontaminated cinder is then solidified on the metal surface, and is carried down into or below the bath of molten iron in a continuous stream, which, in rising up through the iron, combines with the impurities of the latter. On the expiration of the five or ten minutes, the iron begins to thicken, and the motion is stopped. The heat is then raised, so that the cinder shall be perfectly liquefied, and float over the iron. That cinder contains all the impurities which have been liberated from the charge, and it is essential to prevent its further contact with the iron. The vessel is therefore brought into such a position that the tap-hole shall be just over the level of the iron, which by this time has become partly pasty. The puddler gently pushes back the iron, and the cinder is made to run off. The tap-hole, by a slight motion of the vessel, is then brought high enough over the level of the iron, and is stopped up. The heat is again raised, and the furnace is put in motion at a velocity of from six to eight revolutions a minute, by which means the charge is dashed about violently in the furnace. Should a sufficient degree of decarburization not have been produced at that point of the operation, then the liquidity which the iron will assume under the increased temperature will prove the fact. A high temperature being kept up, and the charge being continually turned over, the particles begin to adhere, when the velocity of the apparatus is lowered to from two to three revolutions a minute, upon which the ball then speedily forms. Should any loose pieces be detected in the furnace, the puddler moves them all to the same side of the ball, and by giving a partial rotation to the furnace he causes the ball to fall upon them, and thereby forms them into one mass. The puddler solidifies the front end of the ball by a few blows from a tool applied through the stopper-hole. The props of the movable piece are then removed, and the flue hanging from the overhead rail is moved away. A large fork, suspended from a crane, is moved into the vessel along one side, and the ball, which, by a turn of the vessel, is rolled on to the fork, is removed by means of a crane. The ball is then worked in a squeezer. The requisite quantity of cinder and metal is again charged. The flue is replaced, and the process continued. From eight to ten charges are made before any refettling is required, when the parts most worn are repaired. The bloom comes from the squeezer in a very solid condition, and is either reheated or rolled off into puddled bar, and so on, at once.

Whilst Danks was engaged perfecting his machine in America, Spencer was also actively at work in this country experimenting with a revolving puddling machine. Much labour has been expended in England in this direction, and no one has worked harder and been more indefatigable than Wm. Menelaus, the manager at Dowlais; in fact, he produced a machine almost identical with that of Danks, described in the Proceedings of the Inst. of Mechanical Engineers, June, 1867; but there was one difficulty he could not surmount, and that was finding a suitable fettling or lining for the interior of his furnace. Spencer has succeeded in overcoming this difficulty by using as a lining to his furnace the cinder produced by heating wrought iron in mill, balling, or other furnaces, technically called *best tap*. It is a very pure oxide of iron free from silica, and is easily reduced to the liquid state. The first puddling machine upon Spencer's principle was erected by himself at Richardson and Sons, West Hartlepool Rolling Mills, in 1870. Figs. 4365 to 4367 are of a second machine erected at the same works, capable of puddling 10 cwt. a heat. Fig. 4365 a general plan view of the fire-grate and stack, with the converter on revolving chamber between them; Fig. 4366 is a longitudinal vertical section of these; and Fig. 4367 is an end elevation of the revolving converter on its roller carriage. *a* is the fire-grate, similar in construction to those of ordinary puddling furnaces, and can be worked with an open grate, or with blast if required, a culvert *b* being provided for its introduction. The bridge end of the grate terminates in a cylindrical orifice *c* opening into the converter. The stack *d* has also an orifice, neck, or throat *e*, leading thereto out of the converter. Near the bottom of the stack is a door *f* with a spy hole f^1, through which the operation of conversion can be observed. By inspecting the end elevation, Fig. 4367, it will be noticed that the interior of the converter is composed of four sides arranged in the form of a regular square, and has two ends. Instead of the square, a figure of three or more sides may be substituted, and it need not of necessity be a regular figure. The rhomboidal or skew disposition of the sides with relation to the longitudinal axis of rotation, as shown in Fig. 4365, is preferred; but it does not constitute a feature of the invention, excepting in combination with the forms described.

The converter is a box-like vessel with circular openings g^1, h^1, in its ends *g*, *h*, corresponding and communicating with the circular openings *c* and *e* from fire-grate and into stack. The ends *g*, *h*, are circular vertical plates of cast iron, with rims, flanges, and ribs thereon, and with the open-

4365



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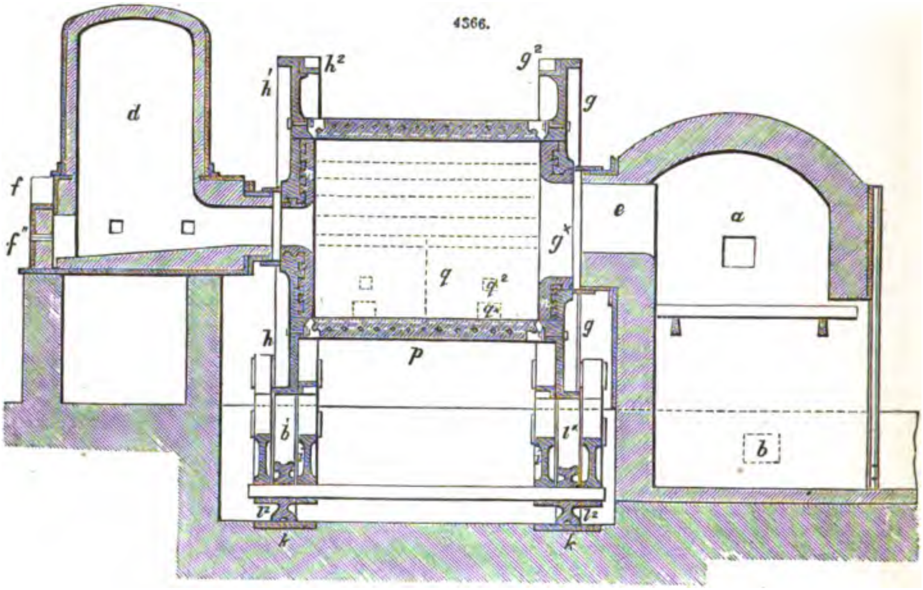
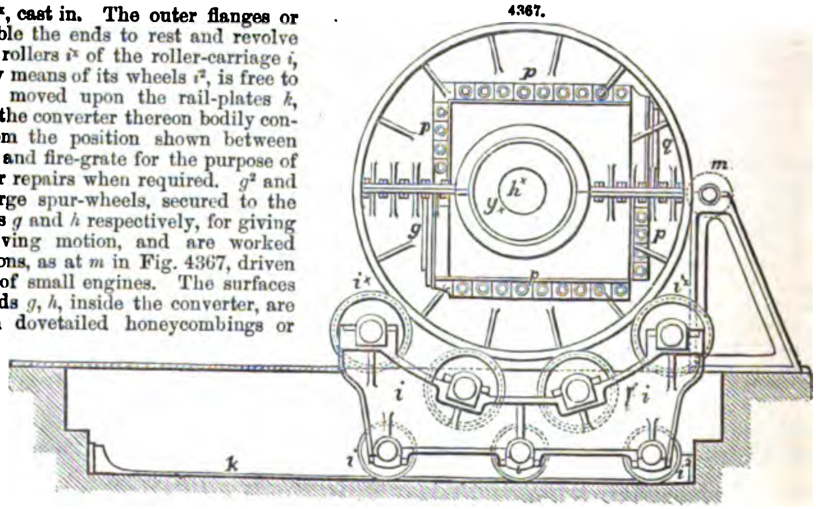


ings g^x, h^x, cast in. The outer flanges or rims enable the ends to rest and revolve upon the rollers i^x of the roller-carriage i, which, by means of its wheels i^2, is free to be easily moved upon the rail-plates k, and with the converter thereon bodily conveyed from the position shown between the stack and fire-grate for the purpose of fettling or repairs when required. g^2 and h^2 are large spur-wheels, secured to the end plates g and h respectively, for giving the revolving motion, and are worked from pinions, as at m in Fig. 4367, driven by a pair of small engines. The surfaces of the ends g, h, inside the converter, are cast with dovetailed honeycombings or

4367.

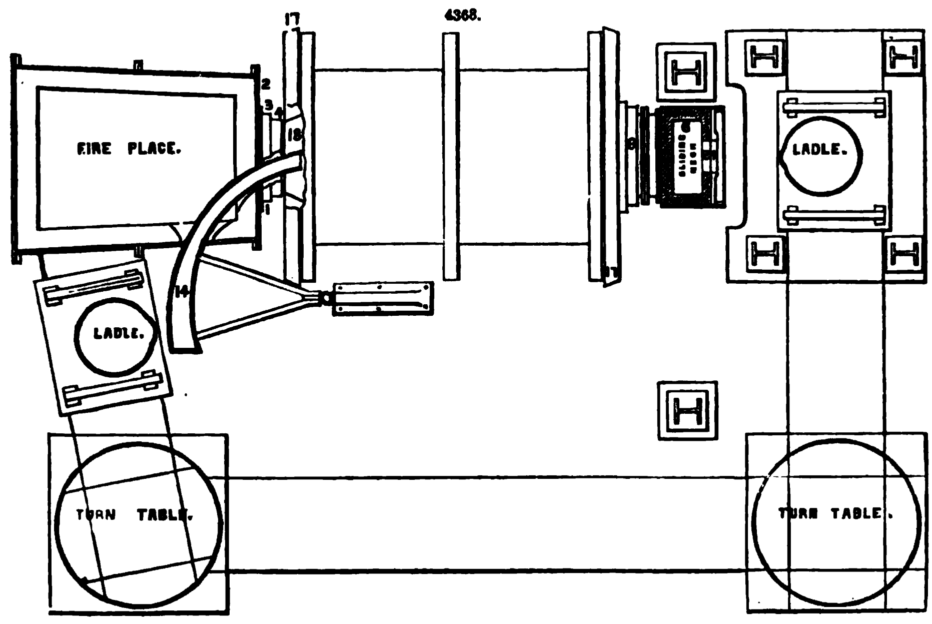


cells for holding the fettling n, as in Fig. 4366. The sides of the converter consist of skeleton cells, trays, or boxes p, lined with fettling and bolted to the ends g, h. On two opposite sides of the converter are hinged honeycombed doors q, having in them charging holes q^1 and spy holes q^2, and these doors may be opened singly or together for the purpose of withdrawing the charge. To explain the revolving chamber clearly, yet briefly, in the inventor's own words, and without reference to the engravings, it is of the rhomboidal form, supported at the ends by large discs at right angles to the axis upon which it is made to revolve. The transverse section is square; longitudinally, two of the sides are parallel to the axis of rotation, and the other two sides, although parallel to each other, are pitched slightly diagonal; the diagonal throw is intended to give to the charge a motion from bridge to flue and the reverse. By the square form and diagonal sides the iron is made to travel over the whole surface in a very effectual manner, even if the speed of rotation be one to two revolutions a minute. Not only are the flat sides found the best for thoroughly agitating the iron, but for allowing the lining to be equally distributed upon the four sides, thus securing a uniformly smooth surface throughout the interior, which can be easily fettled with molten cinder or tap. Where the chamber is connected to the furnace grate and to the stack, loose rings are made to butt against it, allowing it freely to rotate, and very simply securing the joint; the rings are kept well up to their place by levers and balance-weights.

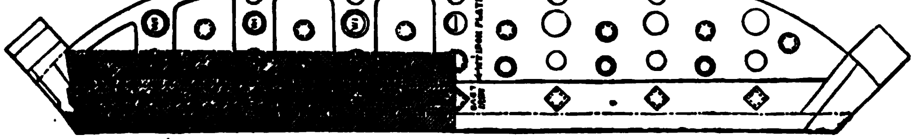
The fettling is secured to the interior of the revolving chamber in the following manner;—Each trough or honeycombed section is filled with molten tap before being placed in position, the ends are made up of tap bricks, cast into moulds of the required shape, and the whole is cemented together with molten tap, charged to the interior through the hole provided in the doors of the machine. The pig iron is first melted in a cupola and then introduced to the converter by means of a wrought-iron trough inserted at the door in the back of the stack, through the body of the stack and the neck of the furnace. The converter is made to revolve slowly, and the metal becomes thoroughly agitated, until it comes to the boil; the vessel is then shortly stopped for a time, and again set in motion, till the metal assumes the granular form and then balled, when it is ready to draw. The whole time occupied is about sixteen minutes.

Spencer has constructed another machine differing from that we have described, as will be seen on referring to Figs. 4368 to 4373. The grate is of ordinary shape and construction, but in size

4368.



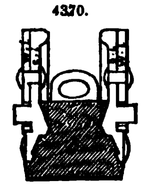
4369.



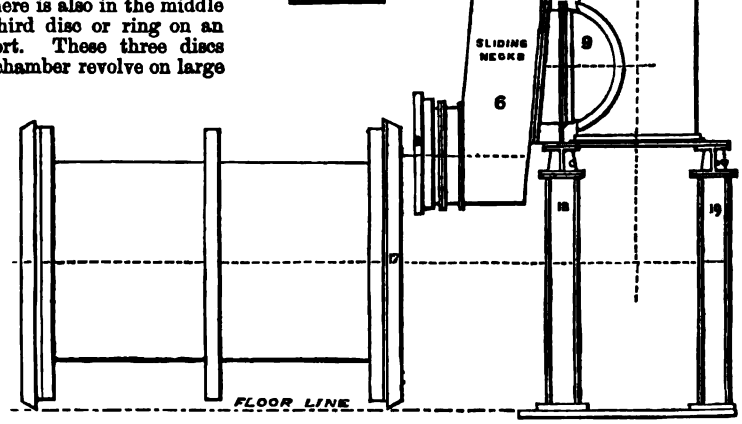
proportionate to the capacity of the revolving chamber. The bridge is a common water-bridge, open on the top and bolted on the end plate of the furnace. The bridge neck has a flange or ring upon it, for the double purpose of confining the brickwork immediately above the bridge, and for supporting a loose ring which serves to form a close joint between the fire-grate and the revolving chamber. The revolving chamber is a long square box, as in the centre of the machine just

described, but longer, the internal dimensions being, when fettled, 9 ft. 6 in. by 4 ft. 8 in. In the present machine all the sides are parallel to the axis of rotation, the advantage of this being that each side can be fettled with the motley cinder so as to have a perfectly level surface, of an even thickness throughout. The sides are composed of open trays or girders of cast iron, placed transversely instead of longitudinally, in order to resist the torsion when revolving. As in the former machine, it is supported at each end by a cast-iron disc, and on account of its greater size there is also in the middle of its length a third disc or ring on an additional support. These three discs which carry the chamber revolve on large rollers fixed on a strong frame and bed-plate beneath the machine. At the flue end of the chamber a movable neck, Fig. 4371, is placed, made of wrought iron, lined with fire-bricks, which forms the junction with the chimney, provided at the lower end with a cast-iron mouthpiece on its side corresponding with that of the sliding neck, and is supported upon girders and columns made sufficiently strong, with the intention ultimately of placing a boiler to utilize waste heat. The fettling, as before, is composed of mill tap, or mill tap mixed with pottery mine, purple ore, roll scale, or any other suitable oxide of iron cast into the sides, and is built in blocks properly moulded against the sides, the whole cemented together by molten tap into one smooth and regular form. This may be called the structural lining. The repairing is done by means of wrought-iron spouts which convey the molten fettling direct from the furnace or ladle to either end or sides, as may be required, and occupies about three minutes. The charge of iron is melted in a cupola, and then carried by a ladle or by a spout to the flue end of the revolving chamber. In the movable neck a small door is open which admits a spout mounted on wheels, which reaches over the joints and dips slightly, so as to allow the iron to run freely and lessen the height which it has to fall. Immediately the iron begins to flow the chamber is made to revolve slowly, thus preventing the iron eating into the bottom and at the same time hastening its conversion. The charging of a ton of iron occupies about three minutes. When completed the spout is withdrawn from the neck of the small door, closed, and the revolving of the chamber is continued. The boil begins in about five minutes, and continues from ten to fifteen minutes. The coming to nature, dropping, and falling, occupy ten or fifteen minutes more, if several balls are required. The operation going on inside the chamber is observed very carefully through spy holes in the neck, and when balls of a sufficient size are formed the machine is immediately stopped. Should the whole heat be wanted in one mass or ball, the chamber is allowed to continue revolving slowly, and firing kept well up for about ten minutes, when it

4370.



4371.



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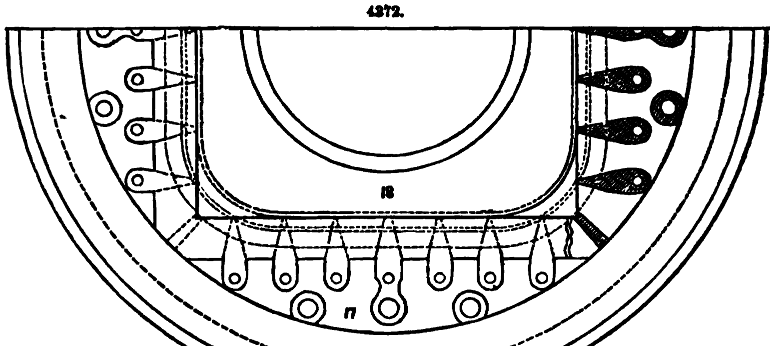

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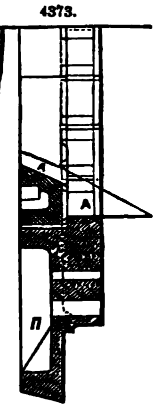
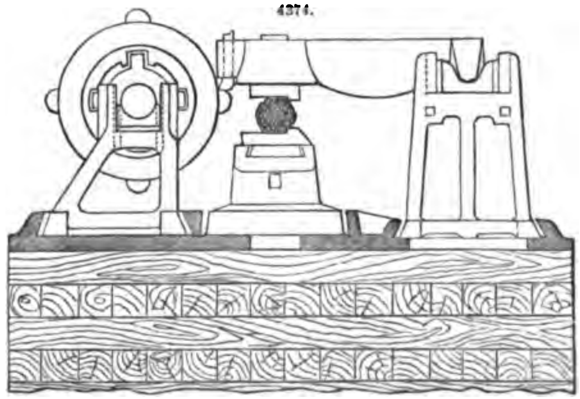


is found that one complete and well-formed ball is the result. The withdrawing of the heat is effected by a pair of long tongs mounted on rollers, attached by a chain to a small hauling engine. The movable neck is found to be a very complete and simple arrangement, as it may be raised or lowered just as easily as the door of the ordinary puddling furnace. The discs of the machine, Figs. 4365 to 4367, were each made of semicircles of cast iron, strongly flanged and bolted together, but the expansion occasioned by the heat soon convinced Spencer that bolts and bars were of little avail, and the discs, instead of remaining round, took a somewhat oval shape. This difficulty has been overcome in the machine, Figs. 4368 to 4373, by making the end discs into two perfect rings, fitting loosely one within the other, with sufficient space between them to allow expansion, the inner ring or centre-piece of each disc being kept in position by bolts passing through flanges provided for that purpose on both rings. It is also further strengthened by having strong hoops of wrought iron contracted on it. As it is of similar size and shape to the inside of the chamber, it absorbs the greater part of the heat, and thus relieves the outer ring of inside strains through expansion. The sides of the revolving chamber are made up of open trays of cast iron of girder form, with wrought-iron plates riveted on them, and held in position by bolts passing through them and through the discs, thus tying the whole together by wrought iron, capable of allowing of any expansion without danger of breaking. The next point is the movable neck or flue drawing, a very simple but effective improvement, and made to slide somewhat like a wedge between the aperture of the revolving chamber and the chimney. The wedge-shape is given to it for the purpose of allowing it to recede from the face of the chamber when lifted, and free itself easily from any cinder which might otherwise clog the joint. Weighted levers give it the requisite pressure, when the machine is in motion, to keep the joints quite tight without the use of wedges, screws, or luting, at the same time admitting it with ease to serve the purpose of a door and screen, and may be opened wholly or partially, as may be necessary, when the heat is being drawn; but as it is most frequently required in such cases to be only partially opened, it still admits of heat being carried to the chimney, or boiler, if there should be one applied to the furnace. It will be noticed that in this machine Spencer has dispensed with the diagonal throw which his former machine had. Immediately on the neck being lifted, a frame upon wheels, carrying a nicely-balanced tongs, is advanced to the doorway and made to grip a ball; the whole is then steadily drawn back by means of a chain attached to the small hauling engine. This process is repeated until the chamber is discharged.

Hammers and Squeezers.—The puddle-balls are delivered by the helper puddler to the shingler, who shapes them into blooms preparatory to passing them between the puddling rolls.

The operation of blooming was formerly performed with heavy hammers; these consolidated the balls by repeated blows, and expelled a large portion of the cinder. During the hammering the bloom was placed endways, receiving a couple of blows in that position to upset it, or condense the particles of metal longitudinally. It is generally considered that where quality is an object, no substitute has been discovered for the hammering. But in yield, the principal object looked to in the manufacture of much of the bar iron of the present day, the modern reciprocating squeezer is superior.

4374.



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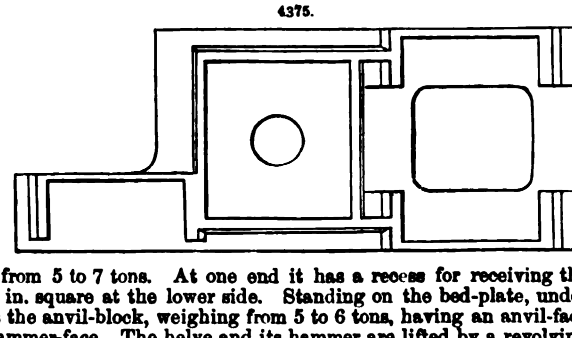
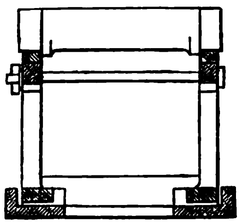


The substructure of a forge-hammer, Figs. 4374, 4375, usually consists of a solid timber bedding, containing from 1000 to 1500 cubic feet of oak, capped by a cast-iron bed-plate, shown in plan, Fig. 4375, measuring about 24 ft. by 7 ft., and weighing from 10 to 12 tons. Two standards, weighing about 3 tons, for carrying the helve are fixed on the bed-plate in strong jaws, and a third, also of nearly equal weight, for carrying the cam-ring shaft. The helve is T-shaped in plan, and measures about 8 ft. long by 6 ft. wide at the centre of vibration, and 2 ft. deep by 12 in. wide in the middle. It weighs from 5 to 7 tons. At one end it has a recess for receiving the hammer-face, which measures 18 in. square at the lower side. Standing on the bed-plate, under the centre of the hammer-face, is the anvil-block, weighing from 5 to 6 tons, having an anvil-face on its upper side similar to the hammer-face. The helve and its hammer are lifted by a revolving cam-ring, 5 ft. in diameter, having wipers or catches on its circumference; these catch in the point of the helve, lift it up, and pass around, permitting it to fall again on the bloom under operation.

Referring to Figs. 4376 to 4388. Fig. 4376 is a cross-section of harness-block, with end view of helve; Fig. 4377, plan of harness-block · Figs. 4378, 4379, section and plan of cam-shaft bearing

4376.



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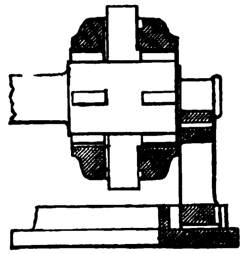

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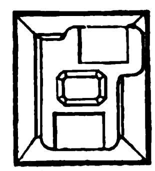

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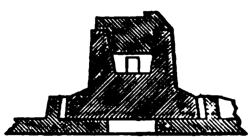

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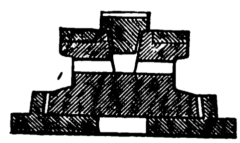

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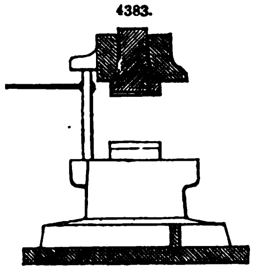

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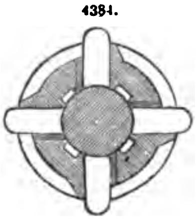
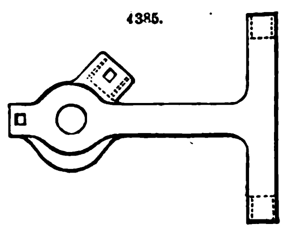
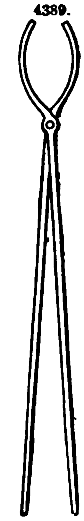


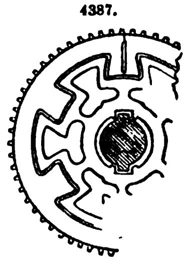
4385.



4389.



4387.



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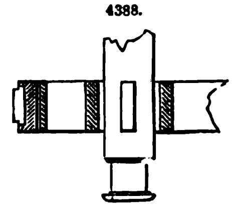

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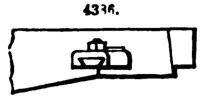


block; Figs. 4380 to 4382, sections and plan of anvil and block; Fig. 4383, elevation of anvil-block, showing sectional helve supported on jack; Fig. 4384, cross-section of cam-ring; Fig. 4385, plan of helve; Fig. 4386, side view of helve-head; Figs. 4387, 4388, elevation and section of driving-wheels; Fig. 4389, shingling tongs.

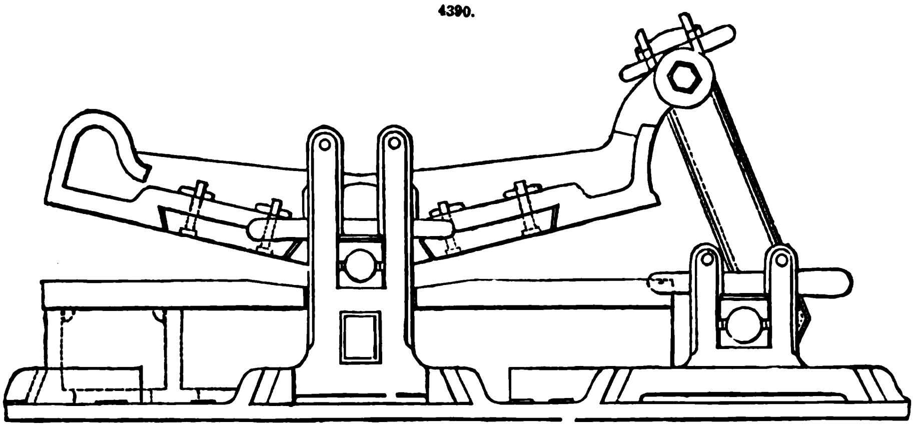
The great strength of these hammers, and the weight of the blows given, may be partly understood from the weight of the castings used in the construction of one of medium size;—Bed, 11 tons; helve-standards, including brasses, 3 tons; helve, 5 tons 10 cwt.; hammer-face, 15 cwt.; anvil-block, 5 tons 10 cwt.; anvil-face, 16 cwt.; standards under cam-ring shaft, 2 tons 10 cwt.; cam-ring shaft, 12-in. bearings, 2 ft. 4 in. diameter in the middle, 7 tons; cam-ring, 4 tons 5 cwt.; four wipers, 24 cwt.: total, 41 tons 10 cwt.

When not working, the helve was propped up clear of the cam-ring on an iron bar made to fit under a projection cast for that purpose. The puddle-ball having been placed on the anvil-face, the helve is lifted off the prop by a boy holding a small iron block underneath the point, and so bringing it within the action of the wipers; the prop being withdrawn, the helve descends on the ball to be again lifted by the succeeding wiper. The height of the lift depends on the relative position of the helve and cam-ring, and provision is made in the standards for any alteration that may be deemed necessary; for a hammer of the dimensions described, the lift would average 16 in. The gearing on the cam-ring shaft in connection with the engine or other prime mover, is proportioned to eighteen or nineteen revolutions of the cam-ring a minute; consequently, with four wipers in the cam, the number of blows ranges from seventy-two to seventy-six a minute. The puddle-balls receive from fifteen to twenty-five blows, occupying from eighteen to thirty seconds, to convert them into blooms.

Figs. 4390, 4391, are an elevation and plan of a double squeezer; Figs. 4392, 4393, sections of the squeezer-arm through gudgeon and through the hammer; Fig. 4394, end of squeezer-arm, showing gudgeon.

The squeezer has now almost entirely supplanted the hammer in the forge. Its first cost is not half so great, the cost of maintenance is diminished in a similar ratio, and if the quality of the iron

4390.



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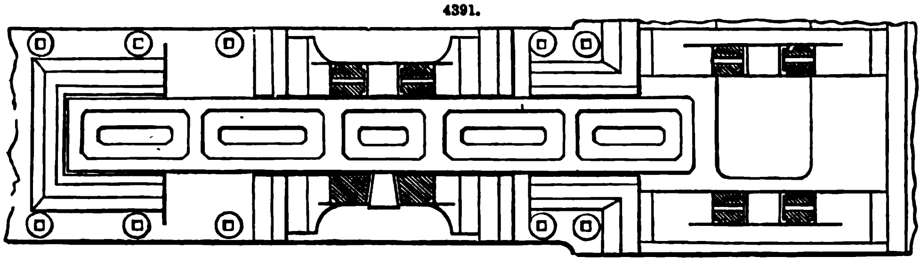

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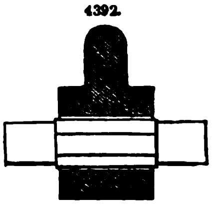

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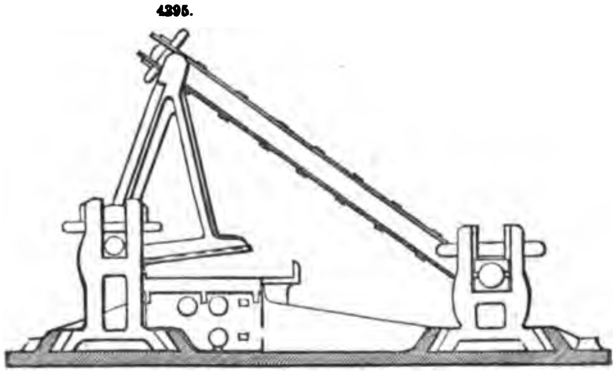

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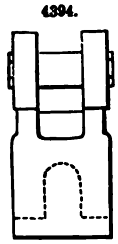

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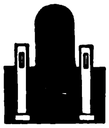

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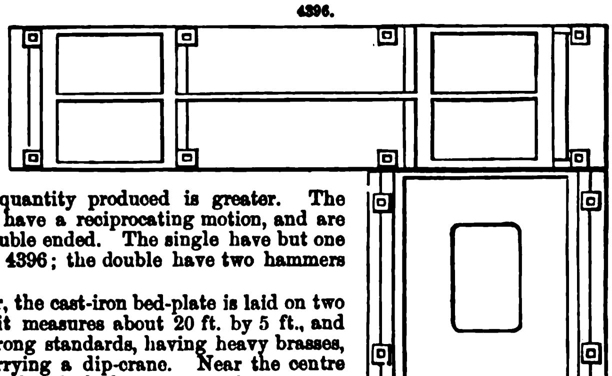


treated is not improved, the quantity produced is greater. The squeezers commonly employed have a reciprocating motion, and are distinguished as single and double ended. The single have but one anvil and hammer, Figs. 4395, 4396; the double have two hammers and two anvils.

For a double-ended squeezer, the cast-iron bed-plate is laid on two longitudinal balks of timber; it measures about 20 ft. by 5 ft., and weighs 6 tons. On one end strong standards, having heavy brasses, are securely fixed to it for carrying a dip-crane. Near the centre two other standards, firmly secured to the bed-plate, carry the squeezer-

arm. This consists of a V-shaped lever moving on a centre gudgeon, one of its ends being connected by a sweep-rod to the crank. Recesses are cast in it to receive hammer-faces, 3 ft. long by 1 ft. 6 in. wide. On the bed-plate a strong horizontal frame carries the two anvil-faces, each measuring 6 ft. by 18 in. When the lever is mounted and in a horizontal position, the inside end of each hammer-face will be 5 in., and the outer end 16 in. from the anvil-face. If the crank has a 16-in. stroke, these distances will be diminished to 4 and 11 in. respectively at the bottom centre, and increased to 6 and 21 in. at the top centre.

The weight of the various pieces composing a double squeezer such as we have described may be stated as follows;—Bedding, 6 tons; crank-shaft standards, 2 tons 10 cwt.; crank, 12 cwt.; standard under anvils, 4 tons; centre standards, 2 tons 16 cwt.; squeezer-arm, 3 tons 5 cwt.; anvils, 1 ton 16 cwt.; hammers, 14 cwt.: total castings, 21 tons 13 cwt.

The puddle-ball is delivered by the helper puddler to the shingler, who moves it forward on the squeezer-anvil until it arrives in contact with the hammer-face. At each stroke of the squeezer-arm the ball is flattened by the pressure, and a portion of the cinder expelled; during the up stroke it is turned over by the shingler towards the fulcrum of the arm, where it is reduced to a bloom about 5 in. in diameter by 18 in. long, after having received in its progress from fifteen to twenty strokes. The upsetting is performed at the extreme end of the squeezer, where its elevation above the anvil gives sufficient height for the bloom to be set up on end and pressed.

The squeezer-crank revolves from forty-five to eighty times a minute, according to the speed at which the rolls are set; the last is a high speed; fifty-six to sixty revolutions is more advantageous. The time occupied in squeezing each ball averages twenty-five seconds when the crank revolves sixty times a minute, giving twenty-five blows altogether to each bloom.

The hammering and squeezing processes differ from each other, inasmuch that in the former the ball is shaped by the impact of the descending hammer; whereas in the latter, the object is attained by simple pressure. In erecting a hammer the chief requisites are a foundation that shall withstand the concussion, and machinery capable of lifting and supporting the helve at the rapid rate of working practised. For this purpose the castings are made very heavy, and weigh above 40 tons, of which nearly 19 tons are in motion. In the construction of the squeezer, the tensile strength of the cast iron employed is severely tried. The crank and centre standards, sweep-rod, and squeezer-arm are subject to enormous strain, and require to be made proportionately strong. From the experience obtained in the working of nine puddling forges, we learn from Truran that the aggregate sectional area of the crank-standards in their weakest place should not be less than 136 in.; the centre standards, 212 in.; and the wrought straps on the sweep-rod, 12 in.

With the weights and proportions given, the duration of the respective moving parts is, for a forge of sixteen furnaces;—Squeezer-arm, ten months; anvils, six months; hammers, eleven months; cranks, three months; brasses to cranks, three weeks. The duration of the hammers and anvils may be increased by casting in them a small wrought-iron pipe bent in a serpentine form for keeping them cool by a current of water, and thus preventing the adhesion of the cinders. The inlet and outlet pipes of the hammer are brought over the centre gudgeon where the vibration is least, and united by a flexible connection to other pipes. By using water in circulation through them, the hammer and anvil will work nearly twice the usual quantity of iron before requiring renewal.

Motion is usually communicated to the squeezer by coupling the crank direct to the end of the bottom roughing roll of the puddling train; in a few works shafting, independent of the rolls, is employed, and the squeezer driven at a reduced speed. The strain is taken off the rolls in this arrangement, but the greater number of bearings in motion and the additional spur-gear increase the resistance to the working of the forge, and probably balance any advantage that might otherwise accrue from a separate connection.

The connection of the squeezer-crank with the end of the roll ought at all times to be made by means of a connecting spindle, as long as circumstances will allow. Connecting direct to the roll end is objectionable, though it is generally done; the lifting of the squeezer-crank causes the roughing rolls to wear unequally, and throws an unnecessary strain on the necks. By employing an intervening spindle this is avoided, and the durability of both rolls and crank is increased. Greater facilities are also afforded by this arrangement for changing rolls, and the stand for the rougher is made more durable by keeping the squeezer farther off. In a forge where the cranks were connected by crabs directly to the roughing rolls, placing a short spindle between increased their average duration from six weeks to five months.

Various modifications of, or substitutes for, the common lever squeezer have been brought out from time to time, and used to a limited extent. The first in the list was an American invention. It consisted of a circular cast-iron well, containing a revolving cylinder of equal depth, placed eccentrically; the least distance between the two was equal to the diameter of the finished bloom, while at the widest the breadth was equal to the diameter of the largest size ball. Motion having been communicated to the inner cylinder by strong bevel-gearing in connection with the engine, the ball is placed in the machine, the inner cylinder, armed with short teeth on its circumference, seizes it, and during its revolution, by a combined squeezing and rolling motion, the ball is reduced to a bloom of the desired dimensions, and delivered at the opposite side to the rougher.

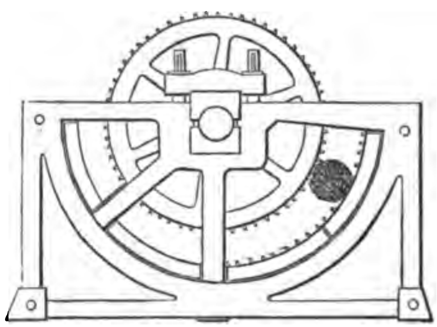
This machine is, taken altogether, a specimen of great ingenuity, but in practice the bevel-gearing and the liability to derangement are great drawbacks to its employment; besides which no effectual means are provided for the upsetting of the bloom, an operation which cannot be dispensed with if the quantity is to remain unimpaired.

An apparatus of a similar kind working vertically is also in use in a few works, Fig. 4397. The revolving cylinder is mounted on two strong cast-iron frames, between which a semi-cylindrical casting is fixed eccentrically to the cylinder. The conversion of the ball into a bloom is effected in the same way as with the American machine, and is subject to the same defects. In one erected at the Plymouth Works an attempt was made to manage the upsetting by means of side blocks acted on by springs; self-feeding and delivering machinery was also provided;

altogether it probably was the most complete of its kind. Its working, however, was not satisfactory, and the reciprocating squeezer, formerly employed, was restored to favour.

In another substitute for the ordinary squeezer, the blooming of the ball is accomplished by passing it between three eccentric rolls, Fig. 798, p. 367, which during their revolution, by compression, extend it laterally to the size for the rougher. The three rolls work on bearing brasses in a strong framing fitted with adjusting screws, and are coupled together by nuts and spur-gearing.

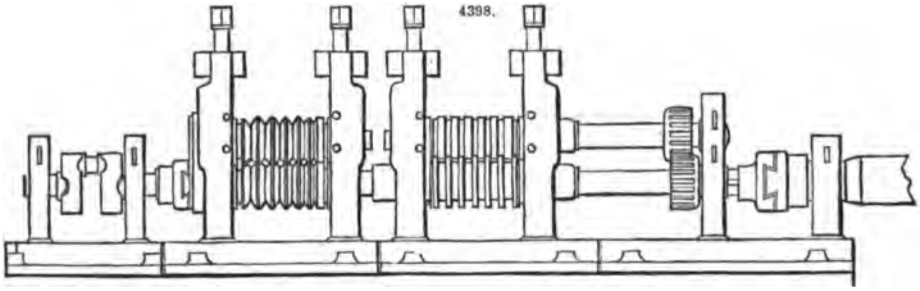
4397.



***Puddling Rolls.*—The puddle-ball having been shaped by the shingler into a bloom of suitable size for the grooves of the rolls, the rougher now takes it in hand. The bloom is passed through the largest groove of the roughing rolls, then through the next smaller, until its sectional diameter is sufficiently reduced for the roller, who shifts it to the finishing rolls, and after passing it three or four times between the rolls, through as many different grooves, produces a finished puddle-bar.**

Fig. 4398 is an elevation of a complete forge train, and Figs. 4399 to 4442 exhibit details. Figs. 4399, 4400, side and front view of fast half of coupling crab; Figs. 4401, 4402, rolls' pinion; Figs. 4403, 4404, clip for keeping rolls' coupling up to their place; Figs. 4405, 4406, loose half of coupling crab; Fig. 4407, elevation of rolls' standards, showing chocks, brasses, roll-necks, and setting screws;

4398.



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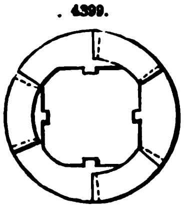

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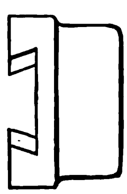

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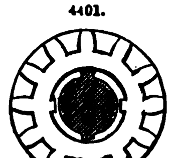

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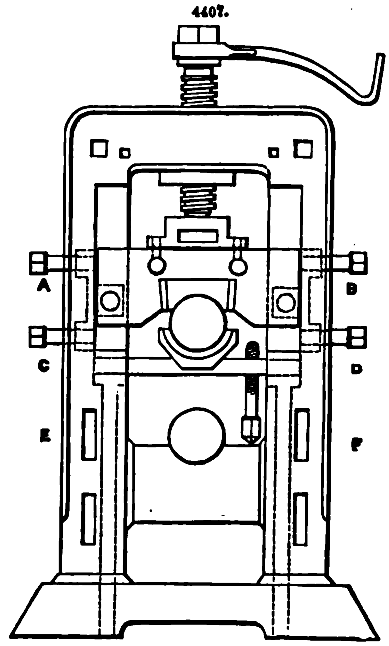

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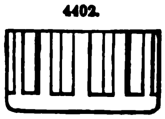

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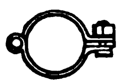

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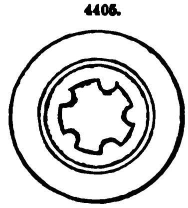

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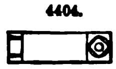

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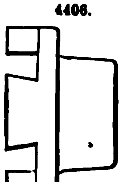

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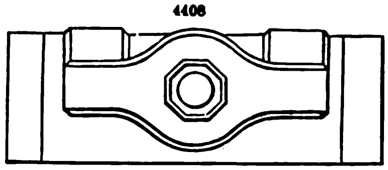
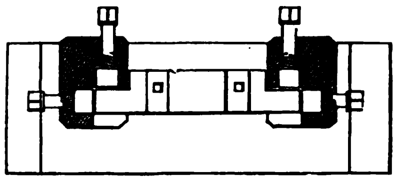


Fig. 4408, plan of standard, Figs. 4409 to 4411, sections of standard; Figs. 4412, 4413, front view and plan of pinion housing; Figs. 4414, 4415, side view and plan of the arm of the squeezer Fig. 4395; Fig. 4416, view of top gudgeon; Fig. 4417, squeezer-crank; Figs. 4418, 4419, standard

for squeezer-crank; Fig. 4420, section of standard, showing gudgeon; Fig. 4421, side elevation of squeezer-arm standard; Fig. 4422, section of same through brass bearing; Figs. 4423, 4424, side

4409.



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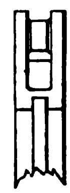

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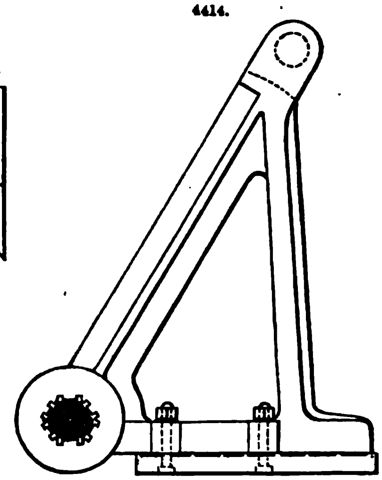

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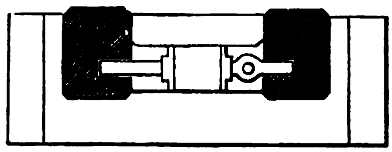

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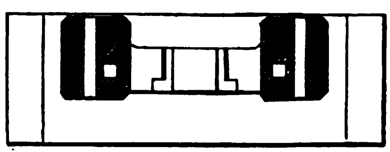

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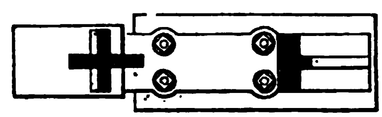

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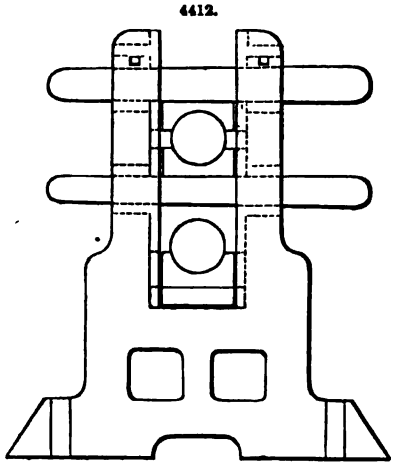

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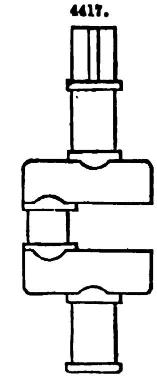

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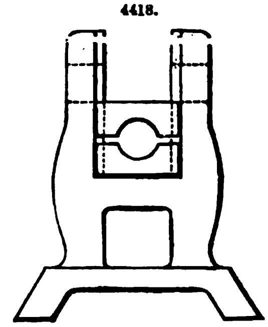

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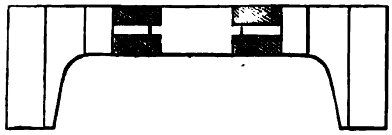

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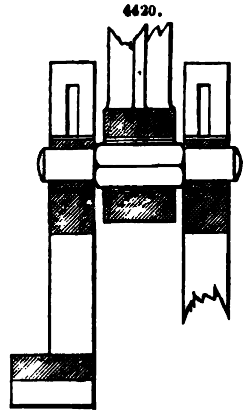

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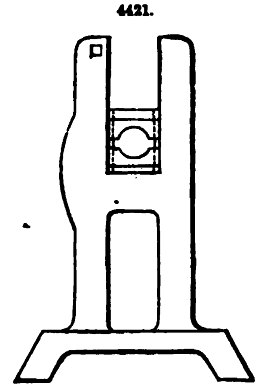

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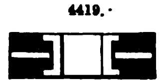
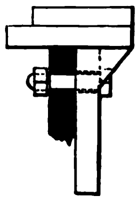


view and cross-section of anvil of squeezer; Figs. 4425, 4426, side and end view of roughing roll to the train; Figs. 4427 to 4429, side and end views of connecting spindle; Figs. 4430 to 4433, section of side and end view of pinion on roll end, with crab for driving squeezer; Figs. 4434, 4435, butt-ends of

squeezer connecting rod; Figs. 4436, 4437, side and end view of coupling box; Figs. 4438, 4439, end of squeezer-anvil; Figs. 4440, 4441, section of rolls, showing loose guides and guides cottered down to rest; Fig. 4442, cinder-plate to go between rolls to keep the cinders out of the bearings.

4423.


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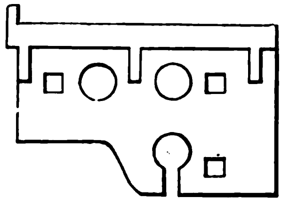

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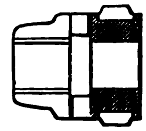

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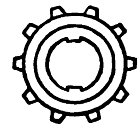

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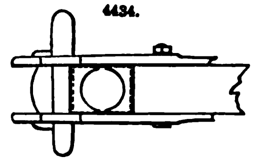

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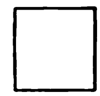

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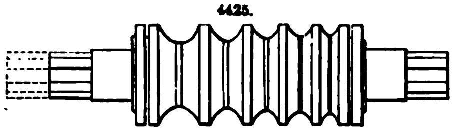

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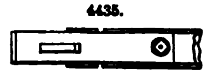

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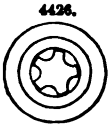

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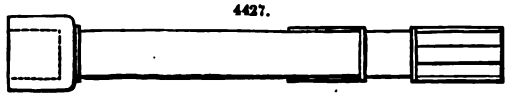

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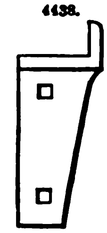

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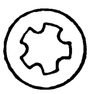

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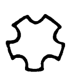

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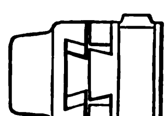

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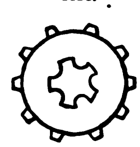

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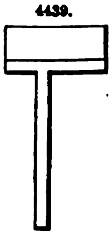

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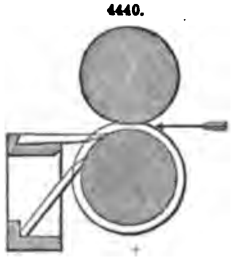

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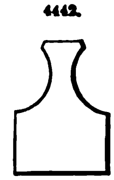


Two pair of rolls form the puddling train, Fig. 4398, one pair for roughing down the bloom, the other for finishing it into a bar. The grooves used in the roughing pair are either oval, Gothic, or diamond-shaped; generally the first two or three grooves are Gothic and the other diamond. The finishing rolls are usually turned with grooves to produce flat bars from 3 to 7 in. wide by ½ in. to 1¼ in. thick. For the narrow bars a pair of finishing rolls will contain a sufficient number of grooves to work iron of two widths; but for the wide bars a pair of rolls are required for each width.

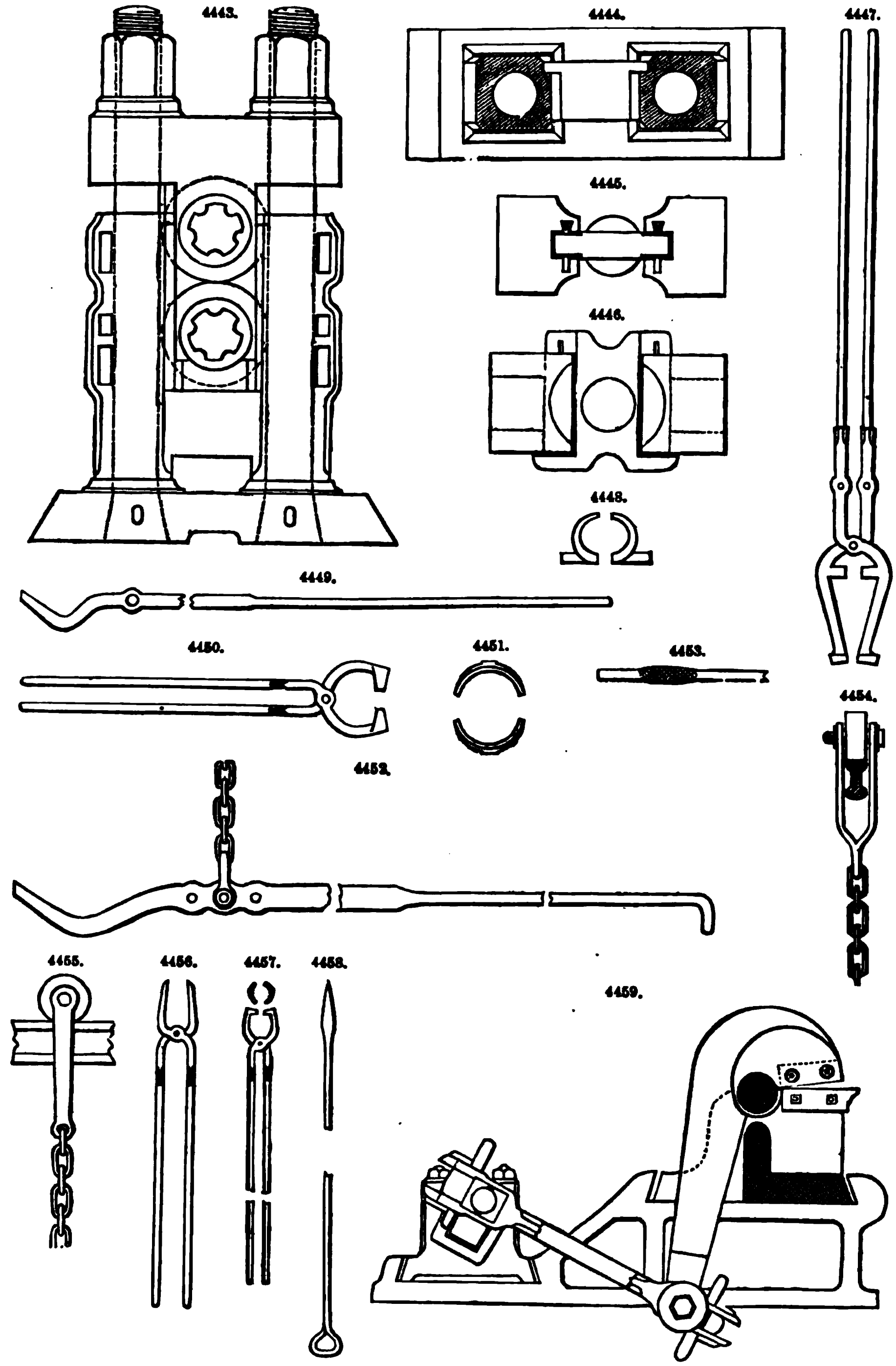
In small forges, and where room is an object, the roughing and finishing grooves are sometimes seen in the pair of rolls, which are then made proportionately longer. This arrangement may be advantageous under certain circumstances, but the greater weight of rolls required to be kept in stock, and the necessity for changing such heavy rolls for every alteration of width, are objections to this plan.

The durability of the necks and brasses is greatly increased by using cinder-plates. A narrow groove is sunk in the body of each roll close to the ends, and a thin wrought-iron plate inserted before lowering the top roll, Figs. 4425, 4442. By this means the cinders, which otherwise get into the bearings, and grind away both iron and brass, are excluded.

The bottom roughing roll is provided with a serrated fore-plate and rest, the bottom finishing with rest and wrought-iron top and false guides. Where water-power is employed, and there is no danger of the guides being drawn in, single guides cottered down to the rest may be used, Fig. 4441. With loose guides, Fig. 4440, the catches of the coupling crabs are constructed so that if the motion of the engine be reversed, the train of rolls is disconnected. Unless this provision were made, the entrance of the cold iron guides on the backward motion would be followed by a breakage.

The puddling rolls are generally 18 in. diameter by 3 ft. 6 in. long between bearings; necks, 10 in. diameter; length of roll over necks, 6 ft. 6 in. A pair will work about a month without

cleaning, and will be worn out, body and flutes, in four or five months. The immense strain on the standards when rolling comparatively cold iron requires them to be of great strength. The aggregate area of metal in the two standards to each pair of rolls should be in the weakest place not less than 230 in.; and the pinion-standards should be of nearly equal strength.

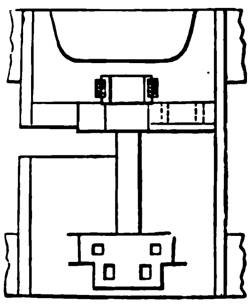


Figs. 4443, 4444, are an elevation and plan of housings for a plate-mill; Figs. 4445 to 4458 show the various hooks, tongs, and other appliances used to manipulate iron at the rolling mill.

The puddle-bar after leaving the rolls is taken by boys to the cutting shears, which in well-arranged forges are placed opposite the finishing rolls. The general practice is to shear the bar hot; but when the lengths and sizes for the mill-piles are not known, the old plan of dragging them out to the bank and shearing cold is followed. Stronger shears are then required, and the labour is performed by men.

Figs. 4459, 4460, show an elevation and plan of a shears for mill-bars; Fig. 4461, part cross-section and Fig. 4462 end of shear-bar; Figs. 4463, 4464, shears for puddled bars; Figs. 4465, 4466,

4460.



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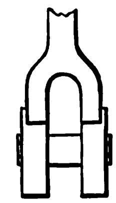

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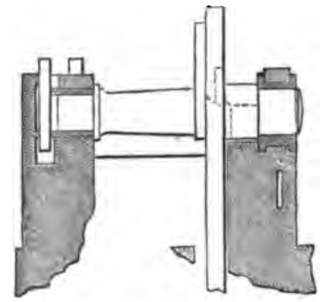

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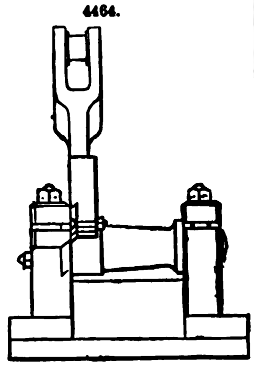

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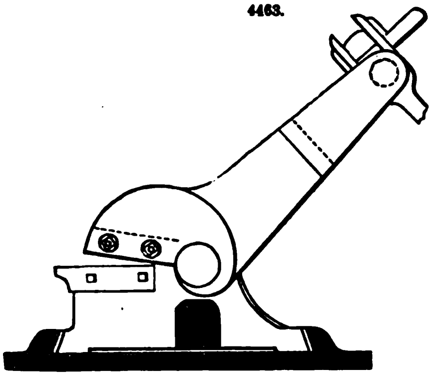

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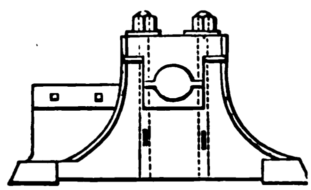

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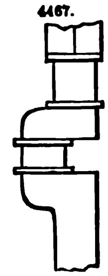

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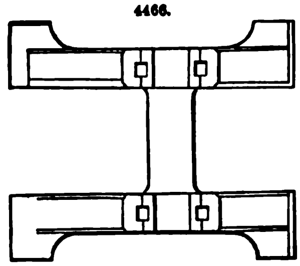

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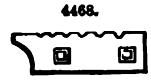

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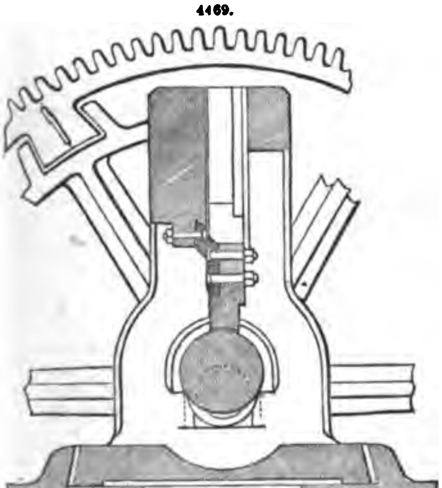

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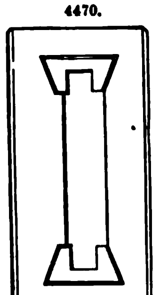

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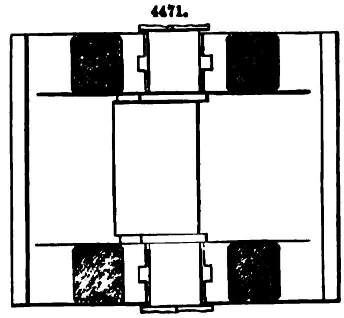
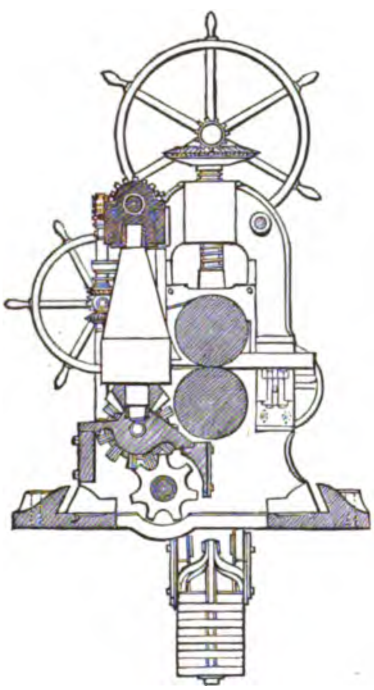


elevation and plan of framing for shears; Fig. 4467, shears-crank; Fig. 4468, knife for cutting bars; Figs. 4469 to 4471, cross-section, plan of frame, and sectional plan of an eccentric shears.

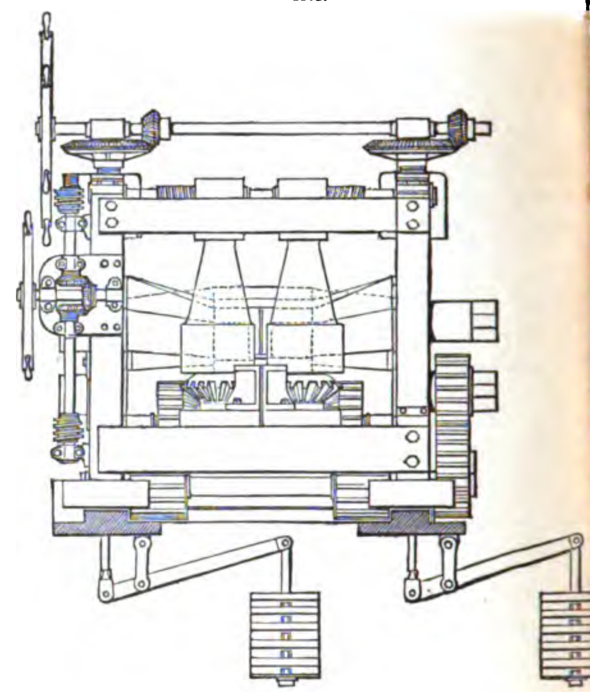
The speed of the puddling rolls ranges from thirty-five to eighty revolutions a minute. The Staffordshire and Derbyshire forges probably work at the lowest speed of any in this country. The Welsh forges are driven from fifty to eighty. The speed preferred by the workmen, and which

is found most advantageous with all but very red short metal, may be placed at fifty-six. But if the iron be very red short, a higher speed is attended with less waste. The shears may be driven at the same rate as the rolls when the latter do not exceed fifty-six revolutions a minute; but when they run faster, the shears should be geared, so as not to exceed this number of cuts a minute.

4472.



4473.



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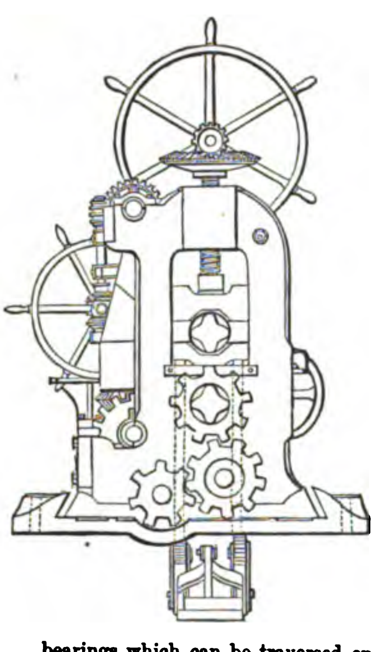

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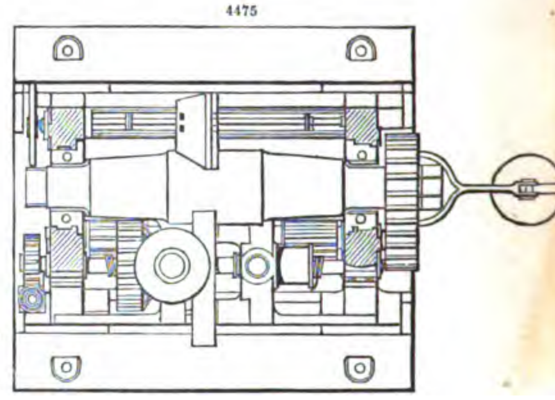


At a speed of eighty revolutions a minute, the bar travels at the rate of four and a quarter miles an hour, and at this rate the workman must follow; at a speed of fifty-six a minute, the bar travels at the rate of three miles an hour.

Universal Rolling Mill.—Figs. 4472 to 4475 illustrate C. Wagner's rolling mill for bars and flats of variable sizes, which has attained the name of a universal mill on account of the facility which it affords for rolling different widths and thicknesses with the same set of rolls. The mill consists of two horizontal rolls mounted and geared in the usual way. To these is added a pair of vertical rolls, fixed in bearings which can be traversed on slides, in a horizontal direction, by means of a pair of right and left screws. The simultaneous movement of the two screws is obtained by a hand-wheel geared to a vertical spindle carrying two worms. These worms act upon wheels, shown as keyed

on to the screw-spindles. By turning these spindles the two vertical rolls are brought closer together or removed from each other, and by these means the width of the bars to be produced in the mill can be fixed at will. The vertical rolls obtain their revolving motion from the driving pinion by means of a pair of bevel-wheels geared into other bevel-wheels which slide on their shaft following the movements of the vertical rolls. The horizontal top roll is held up in its bearings by a pair of counterweights, and its distance from the bottom roll is regulated in the usual way by a pair of screws. Several rolling mills of this kind are in operation in Austria, and have proved very useful and convenient in practice.

Ramsbottom's Reversing Rolling Mill.—The special point in the arrangement of the rolling mill designed by John Ramsbottom is that the rolls are driven direct by the engine, without the intervention of a fly-wheel; and the engine and rolls together are reversed each time that a heat is passed through, the rolling being alternately in opposite directions. The idea of reversing a train of rolls by reversing the engine at each passage of the heat through the rolls was first suggested by Nasmyth, but was, we believe, first applied in this mill.

4476.

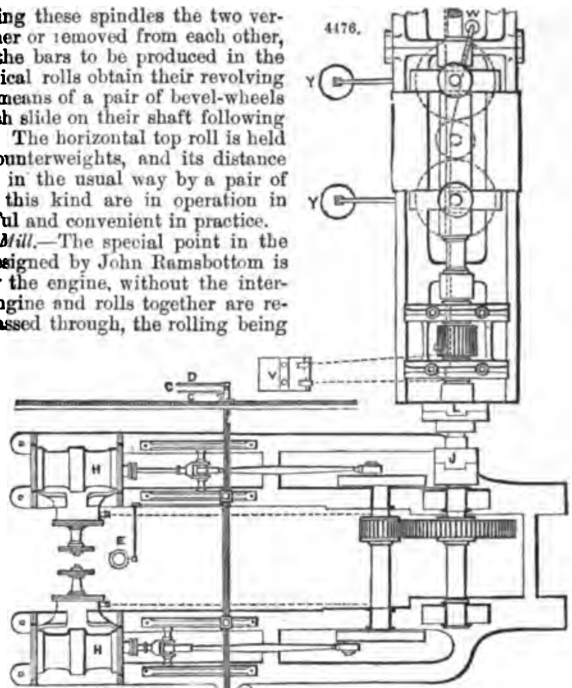
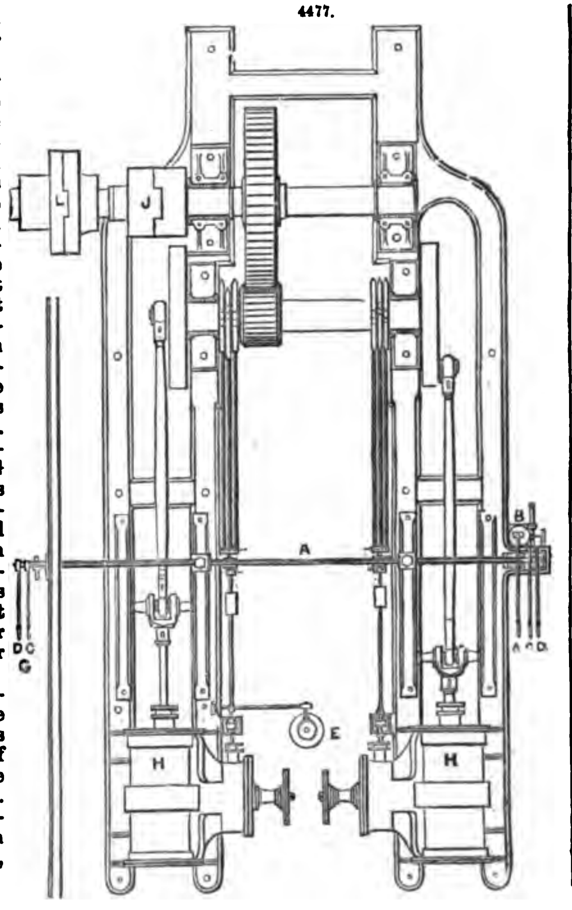


Fig. 4476 is a general plan of the rolling mill and engines; Fig. 4477 an enlarged plan of the engines; Fig. 4478 a side elevation of the engines; and Fig. 4479 a transverse section. They are a pair of direct-acting horizontal engines coupled at right angles, Fig. 4477, and are reversed by hydraulic power without shutting off steam, by means of the arrangement shown in plan, Fig. 4477, and in elevation to a larger scale in Fig. 4480. The reversing shaft A is connected by links to a piston working in a small cylinder B of 4 in. diameter and 10½ in. stroke, the water-pressure being 300 lbs. the square inch. The admission of the water to the cylinder is regulated by a slide-valve worked by the shaft and hand-lever C C. This shaft is prolonged and carried outside the engine-house, as shown in Fig. 4477, in order to place the attendant in a position where he may be able more easily to seize the right moment for reversing. The shaft C is made hollow, as shown enlarged in Fig. 4481; and through it runs a second shaft with hand-lever D D, which regulates the main steam-valve E of the engines by the lever and connecting rod F. By this means the attendant standing outside the engine-house at G and in full view of the rolls has complete command over the engines by the two handles C and D. A hand-lever is also fixed on the reversing shaft A, as a provision for reversing the engines in the event of any accident occurring to the hydraulic gear or any deficiency in the water supply.

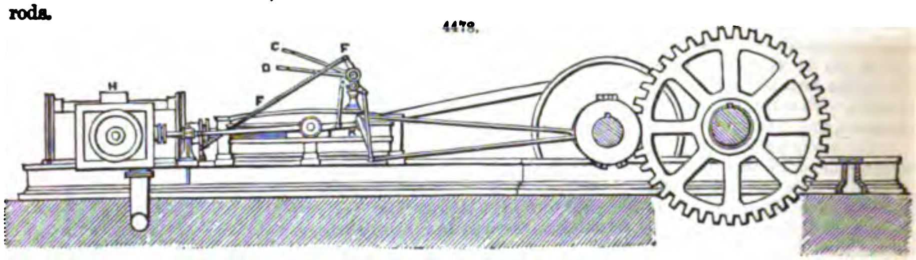
The engines make 3¼ revolutions for one revolution of the rolls, and the speed of piston is about four times (4·14) that of the circumference of the rolls. The cylinders H H, Fig. 4477, are 28 in. diameter with 4 ft. stroke. The expansion link K, Fig. 4478, shown to a larger scale in Fig. 4482,

4477.



is the straight link devised by Alexander Allan, and is driven by three eccentrics and rods, two at one end and one at the other, so as to avoid the oblique thrust inevitable with only two eccentric rods.

4478.



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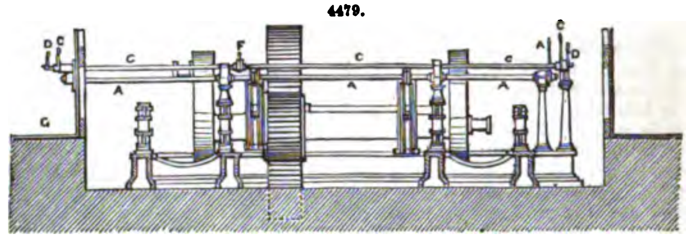
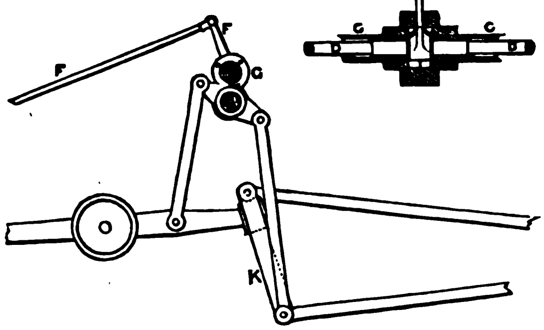
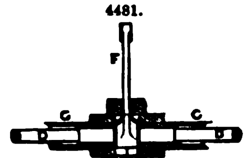


The connection between the engines and the mill train is made, first by means of an ordinary clutch shown at J J in Figs. 4476, 4477, and secondly by a friction coupling designed by Ramsbottom, and shown in position at L L. This friction coupling is shown enlarged in Figs. 4483, 4484. The disc M is keyed on the driver-shaft N, and a smaller disc O is mounted wobbler-fashion on the mill-shaft P, and tightly compressed between the driver-disc and a loose ring I, bolted to the driver-disc. Annular segments of alder-wood packing ¾ in. thick are interposed between the discs to increase the bite, and are placed so that the fibres run radially to the shaft.

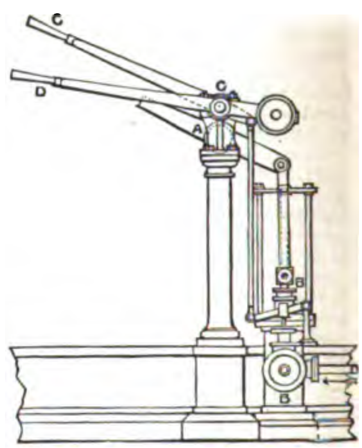
4482.



4481.



4480.



This friction coupling is capable of transmitting the whole power of the engines in regular work; but if from a sudden obstruction the motion of the rolls is arrested, the driver-disc slips round the follower without moving it, and no injury is sustained by any part of the machinery. In ordinary roll trains it has sometimes happened that the breaking spindle has broken, and that the broken end has acted as a lever to shift the engines from their bed; but by the present arrangement the probability of such an occurrence is very much diminished, and many stoppages and breakages are avoided.

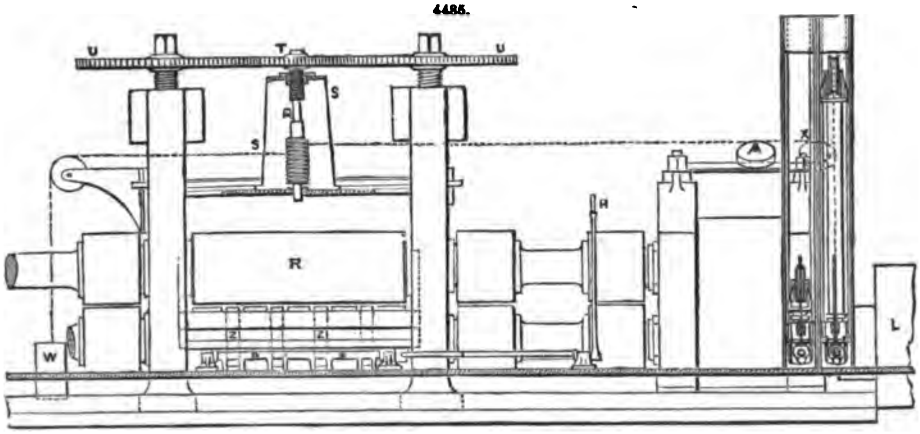
The engines are of such power that there is no necessity to do more than just start them before the heat enters the rolls. Thus the heavy fly-wheel usually employed is not required, and consequently the engines are easily reversed; neither is there any expenditure of steam except at the time of rolling. For the same reason the wear and tear of machinery and the necessary lubrication are reduced in this mode of driving the rolls. Instead of the heavy fly-wheel employed in the ordinary arrangement of rolling mills as a reservoir of power, in which the power of the engine is previously accumulated ready to be concentrated upon the work at the time

of rolling, the boiler is made to serve as the reservoir of power in the new rolling mill; and it has this great advantage, that whereas the fly-wheel contains only a limited store of power, which continues diminishing during the time of application, the boiler supply is practically unlimited, so that the rolling power continues constant throughout the time of operation.

In the rolling of puddled slabs for the frame-plates of locomotive engines, which are reduced 3½ in. in thickness at one heat in the rolls, about twenty-one reversals of the rolls are required. These are effected with great ease by the arrangement above described, the shock being transmitted to the elastic cushion of steam in the cylinders of the engines. This handiness allows of either iron or steel plates being passed through both the roughing-down rolls and the finishing rolls at one heat; and the work is thus done with a minimum expenditure of heat and waste of metal. It has been found on trial not at all difficult to reverse the engines together with the whole train of rolls as many as seventy-three times in one minute.

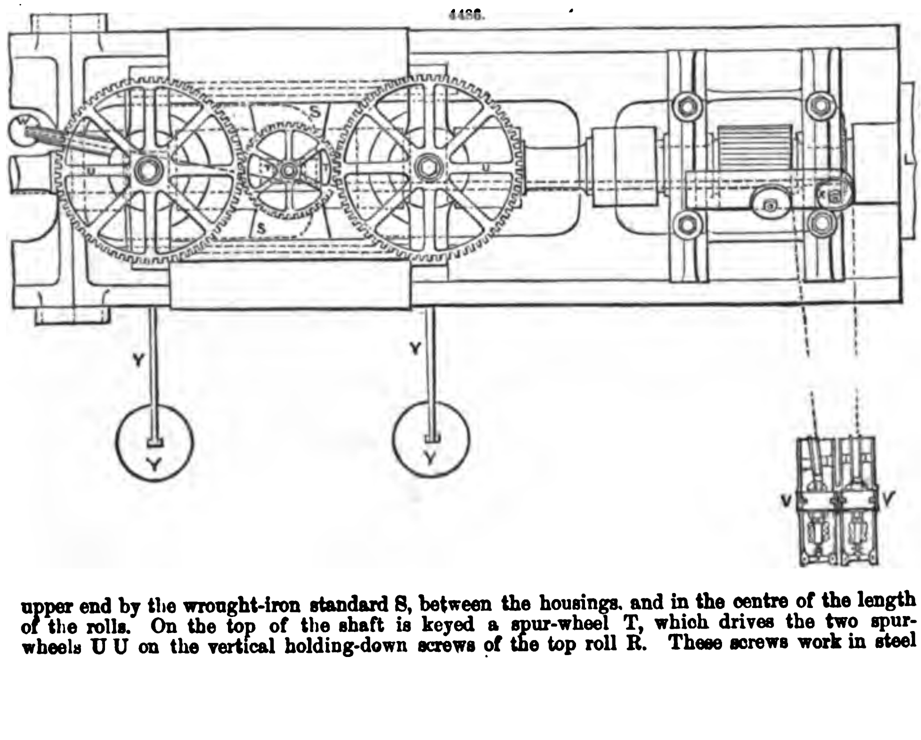
There are two pairs of rolls, one for roughing down and the other for finishing. The roughing-down pair are 24 in. diameter by 6 ft. length; they are shown in elevation and plan, Figs. 4485, 4486; Fig. 4487 is an end elevation; and Figs. 4488, 4489, are transverse sections through the housing and through the rolls.

4485.



In these rolls a new description of tightening-down gear has been designed, in order to obtain greater facility and accuracy in tightening down the rolls, and to ensure the top roll being at all times perfectly parallel to the bottom roll. This gear is shown in Figs. 4485, 4486, 4489. It consists of a vertical wrought-iron shaft Q, carried by a cast-iron bed-plate and supported at the

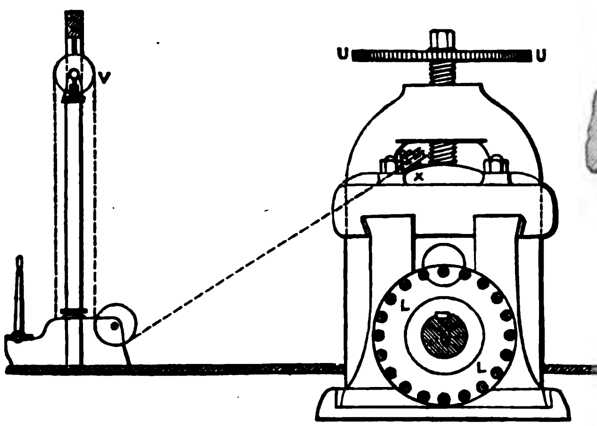
4486.



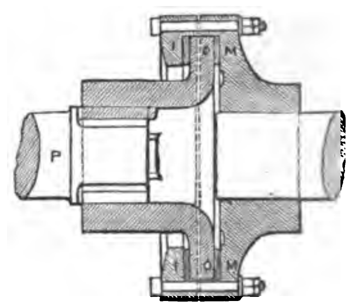
upper end by the wrought-iron standard S, between the housings, and in the centre of the length of the rolls. On the top of the shaft is keyed a spur-wheel T, which drives the two spur-wheels U U on the vertical holding-down screws of the top roll R. These screws work in steel

nuts let into the housings, Fig. 4488, and the top bearing of the centre shaft Q is also a corresponding screw working in a brass nut, so that the centre spur-wheel T rises and descends simultaneously with the two outer spur-wheels U U when the gear is in motion. A vertical hydraulic ram V, Fig. 4485, is placed in a convenient position near the rolls; and a chain, shown by the dotted line, is fastened at one end to the barrel of the ram, carried thence over the pulley on the ram-head V, down again to the fixed pulley below, and thence round a guide-pulley X on the nearer roll housing to the spiral chain-barrel upon the lower end of the

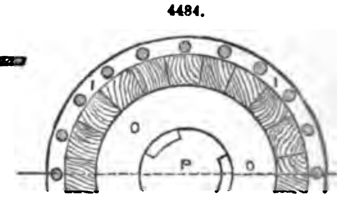
4487.



4483.

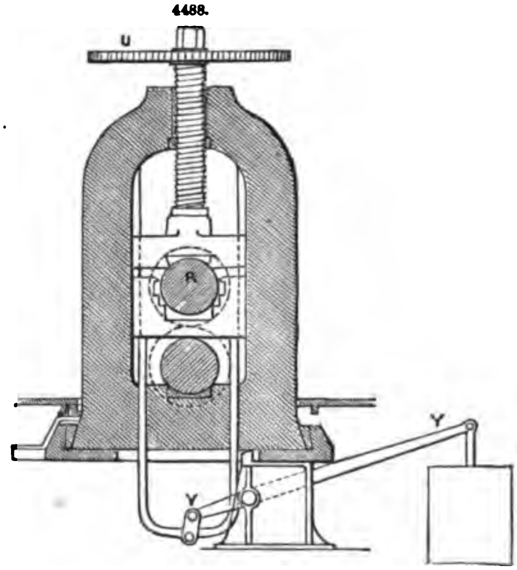


4484.

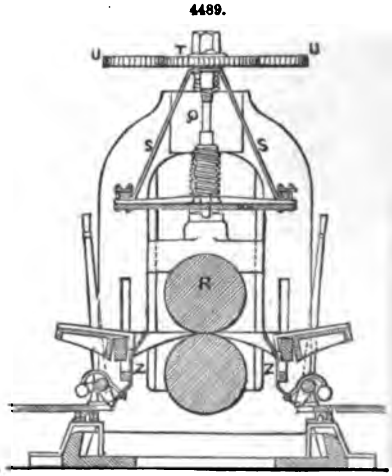


vertical centre shaft Q. The chain makes a few coils round the barrel, and the end is fastened to the barrel near the top. Another chain is fastened to the barrel near the bottom, and after a few coils round the barrel quits it in nearly the same horizontal plane as the first chain, and passes off on the opposite side and over a guide-pulley on the farther housing; a weight W is suspended at the end of this chain, heavy enough to overhaul the other chain and slack back the tightening-down screws of the top roll, when the water-pressure is shut off from the hydraulic ram V.

4488.



4489.



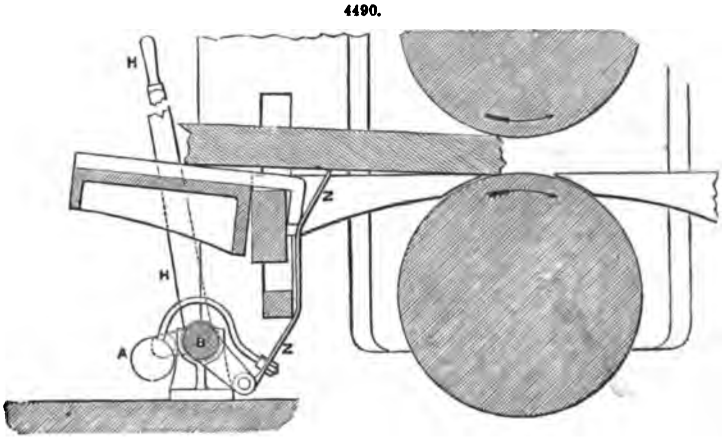
When a slab has entered and passed once through the rolls, the engines are reversed, and the water-valve being opened the ram V rises and hauls in the chain, driving the chain-barrel and causing the tightening-down screws U U to descend and lower both ends of the top roll simultaneously to the required extent. This process is repeated after each passage of the slab through

the rolls. When the rolling is completed, the water is released from the ram, and the ram falls, while the counterbalance weight W on the second chain winds up the tightening-down screws to their original position; and the usual counterbalance apparatus Y, Figs. 4485, 4488, applied to the top roll R, causes it to rise with the upper chocks.

The head V of the hydraulic ram, Figs. 4485, 4487, carries an index finger, which by means of graduations on the guides enables the attendant to give with accuracy the requisite amount of lowering of the top roll at each reversal, and thereby to reduce each slab with certainty to exactly the same thickness. As an additional precaution in rolling a set of slabs all to the same thickness, a chalk mark is made on one of the spur-wheels U, after the final rolling of the first slab; and at the final rolling of each successive slab of the same set a stop is placed in the teeth of the spur-wheel at this mark, stopping the screwing down always at the same point, and thus preventing the possibility of a mistake in the finished thickness of any slabs of that set. The total vertical motion given to the roll by the hydraulic ram is $3\frac{1}{2}$ in., while the stroke of the ram is 6 ft. $2\frac{1}{2}$ in., consequently the movement of the ram is twenty-one times that of the roll, and the indication by which the tightening of the rolls is measured being thus magnified twenty-one times gives great accuracy in the adjustment.

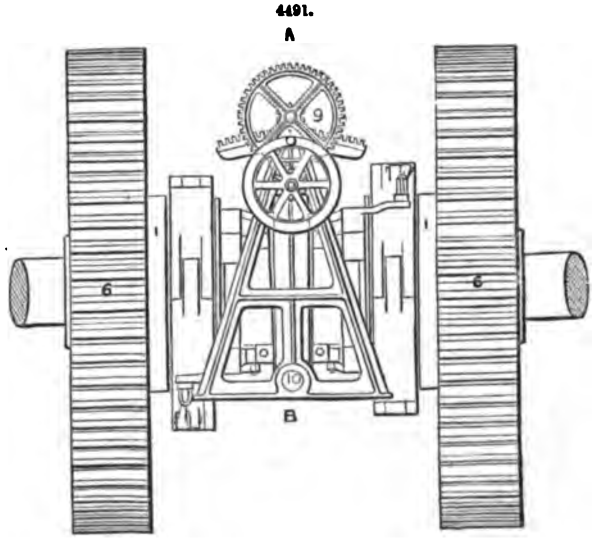
By this system of gearing the two tightening-down screws together by means of the intermediate spur-wheel, the top roll is made to move always truly parallel to the lower roll, and there is no possibility of one end of the roll descending more than the other. Thus the two surfaces of the slabs rolled are made perfectly parallel to each other, with a uniform thickness throughout the entire width of the slab.

4490.



In the finishing rolls the same tightening-down gear is employed. These rolls are of cast iron chilled on the circumference, 24 in. diameter by 7 ft. length; and they differ in no important respect from the roughing-down rolls. As the finishing rolls require only a small vertical motion, no counterbalancing gear is applied to the top roll as in the previous pair, the bottom chocks of the top roll being supported by the ordinary transverse spring beams passed through the housings.

4491.



In order to facilitate the introduction of large slabs into the roughing-down rolls, a set of bent levers Z Z, Figs. 4485, 4489, shown to a larger scale in Fig. 4490, are attached to a horizontal shaft B running along the ground parallel to the rolls; and by means of a hand-lever H on the shaft all these levers are simultaneously brought up under the slab, and by a slight movement the slab is then lifted into the rolls. Each of the levers is attached to the shaft B by an arm and pin joint, so that it can yield to any inequality on the surface of the slab; and it is brought up again by the overhanging counterbalance ball A.

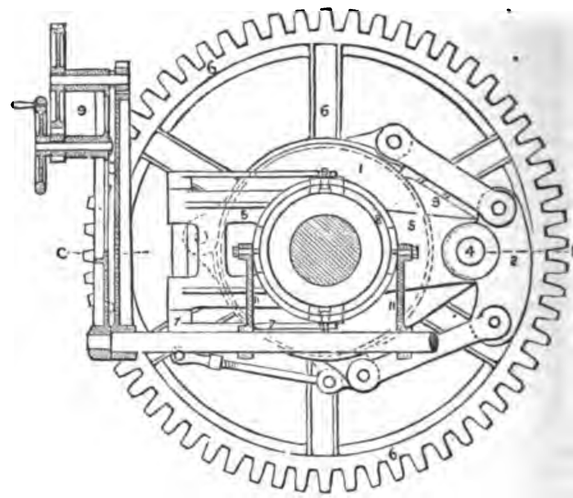
From the fact that the train of rolls driven in this manner is only in motion while the heat is being passed through, it is not found necessary to use a stream of water for lubricating the roll bearings in the ordinary manner; but all the journals are truly fitted in the bearings, and are lubricated with oil and tallow.

Napier's Differential Friction-Gear for Reversing Rolling Mills.—Fig. 4491 is an elevation of

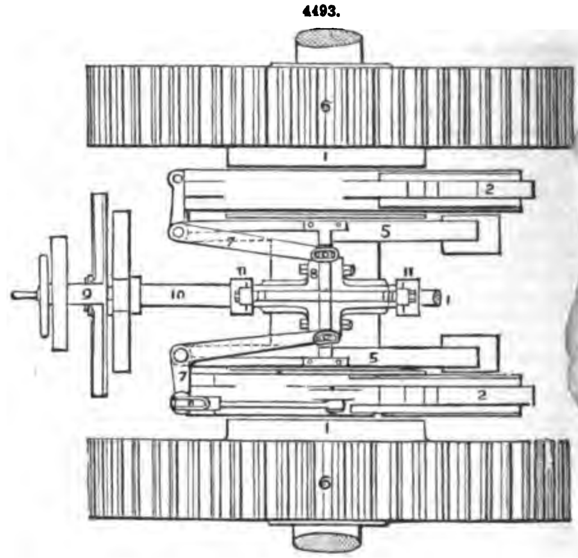
Napier's friction-gear; Fig. 4492 a section through A B; Fig. 4493 a plan; and Fig. 4494 a section through C I, with the friction-straps removed. Fig. 4495 a self-acting friction-brake, which is the basis of the differential clutch.

In Fig. 4495, 1 is the friction-wheel, 2 the differential lever, and C D E the friction-strap connected by links to the differential lever; 3 is what is termed a thrust-block, in the exterior concave part of which the differential lever rests, and the hole through the differential lever for the fulcrum-pin is slotted a little on the part farthest from the friction-wheel, by which arrangement all the radial strain which, if there was no thrust-block, would be borne by the fulcrum-pin, is taken off it and transmitted to the friction-wheel, leaving only the tangential strain to be borne by the fulcrum-pin. The principal object of the thrust-block is to relieve the fulcrum-pin of a great part of the strain that it would otherwise have to bear; but it has the secondary result of increasing the brake or clutch by about 50 per cent., for the friction of the thrust-block on the friction-wheel is about the average between that of the two segments C D and D E, of which the friction-strap consists.

4492.



4493.



Referring to Figs. 4491 to 4494, in which the fulcrum-pin F of Fig. 4495 becomes the crank-pin or driving pin. The cranks 5 are keyed to the shaft, and the spur-wheels 6, to which the friction-wheels 1 are attached, run loose on the shafts, and are driven in opposite directions by any convenient arrangement.

The friction-straps are alternately made to grip and release their respective friction-wheels by means of the bell-cranks 7, worked by the sliding ring 8, which is worked by the hand-gearing 9 through the axle 10, to which are keyed the two levers 11.

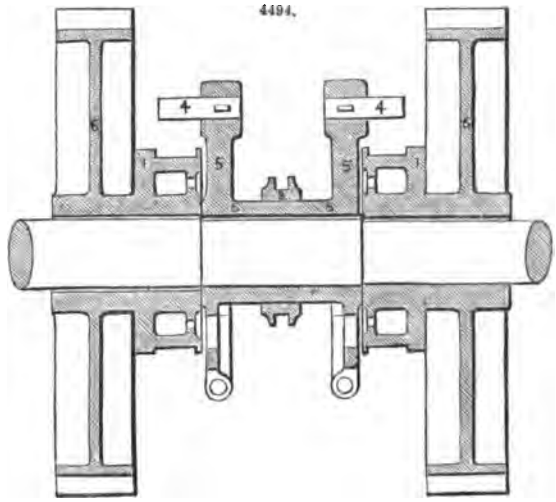
When the sliding ring 8 is in the middle between the two cranks, both clutches are out of gear, and if it is moved towards one or the other crank, the corresponding clutch is put into gear by allowing the friction-strap to grip its friction-wheel, when that wheel drives its friction-strap, and the strap the crank by its crank-pin. Though this plan of clutch may be made self-holding, it may at the same time be thrown into gear when going at great speed without the slightest shock, for the self-holding action does not come into full play till the friction-strap and its respective friction-wheel have acquired the same relative velocity.

In a rolling mill at the Butterley Iron-works, in Yorkshire, where the rolls, which are 22 in. diameter, make the rapid speed of forty-five revolutions a minute, they can be reversed from full speed one way to full speed the opposite way in about three seconds without the slightest shock; and smaller machinery, making two to three hundred revolutions, is reversed in a fraction of a second from full speed one way to full speed the other, without the slightest indication of a shock.

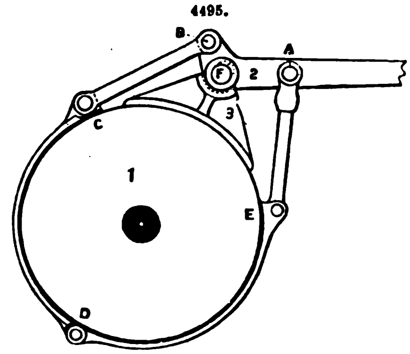
Stevenson's Reversing Gear.—Figs. 4496 to 4499 are sections of a mill-shaft with gear-wheels and conical clutch as arranged by Allan Stevenson. The shaft, 33, carries two spur-wheels, 35 and 36, which, by means of well-known gearing, are continuously driven in opposite directions. The wheels, 35 and 36, are formed with hollow conical rims, 37, to frictionally engage with convexly-coned parts, 38, upon a duplex sliding-piece, 39, between them, and they are fixed on elongated bosses, 40, carried on brass bushes, 41, on the shaft, whilst collar-pieces, 42, are bolted on the shaft

in halves to sustain the end thrust of the coupling action. The position of each brass bush, 41, is such that the plane of the centre of gravity of the wheel, 35 or 36, may be at the middle of its length, or as nearly so as possible, the tendency of the wheels when running loose to wear the bushes conical will be thus avoided. For this purpose the bushes, 41, are elongated at their inner ends; and to admit of this elongation, the clutch-piece, 39, is made bell-shaped. The convexly-coned parts, 38, of the clutch-piece, 39, are made in separate segments, fixed and adjusted by screw-bolts, and on wear taking place they can be readjusted with great facility. The conical surfaces are preferably made as shown, with a very acute inclination to the shaft, and the angle should in no case exceed half a right angle; for as a right angle, that of a plain disc, is approached, not only is a much greater pressure required to give the requisite bite, but the action of getting into contact is also more sudden and liable to produce injurious concussion. The duplex clutch-piece, 39, is moved to put one or other of the wheels, 35 or 36, into gear by a transverse key, 43, of hammered cast-steel working in a slot cut through the shaft, 33, and fixed in a rod or spindle, 44. The spindle, 44, is moved by means of a steam or hydraulic cylinder, but Stevenson prefers steam to hydraulic pressure, as the elasticity of the steam renders the engaging action both more gradual and the reversals more speedy. The contact pressure required is slight, and a very small steam-cylinder working through levers, as in Figs. 4498, 4499, is quite sufficient to give the requisite driving grip.

4494.



4495.



Slitting Mill.—Fig. 4500 is a general view; Figs. 4501, 4502, side and front views; Figs. 4503, 4504, plan and sectional plan of a slitting mill, used for forming rods which are square or rectangular in section; Figs. 4505, 4506, are views of the connecting spindle. The machine consists of a pair of rolls having a series of narrow, sharp-edged, parallel collars, with the intermediate depressions or grooves of the same width. The collars and grooves are produced in the lathe, and the former work between the latter, leaving spaces sufficient for the rods to pass through.

We subjoin, in the following Tables taken from Truran, the principal dimensions of such parts of the machinery as demand special care in their construction; they were taken from forges which had been at work some years.

DIMENSIONS OF ENGINES AND MACHINERY AT PUDDLING FORGES.

Name of Works.	Description of Engine.	Diameter of Cylinder in inches.	Length of Stroke in feet.	Number of Strokes a minute.	Diameter of Crank-shaft Bearing in inches.	Diameter of Crank-pin in inches.	Diameter of Driving Wheel at Pitch-line in feet.	Width of Tooth on Face in inches.
Dowlais, 1	Low-pressure condensing beam	45	7·0	22	13·5	7	12·6	15
„ 2	„ „ „	36	7·0	22	12·0	7	13·6	15
„ 3	High-pressure, beam	42	6·0	20	15·5	8	15·0	19
„ 4	„ horizontal ..	37	7·0	23	13·5	6	13·6	15
„ 5	„ vertical	26	4·0	30	10·0	4	11·5	12
Hirwain ..	Low-pressure	30	6·0	20	11·0	5	15·8	14
Forest ..	Water-power	..	..	..	10·0	..	19·0	14

DIMENSIONS OF ENGINES AND MACHINERY AT PUDDLING FORGES—*continued.*

Name of Works.	Thickness of Rim of Wheel in inches.	Number of Teeth in Driving Wheel.	Pitch of Teeth in Driving Wheel in inches.	Diameter of Spur-wheel at Pitch-line in inches.	Width of Spur-wheel over Flanges in inches.	Thickness of Rim of Spur-wheel in inches.	Diameter of Fly-wheel Shaft-bearings in inches.	Diameter of Fly-wheel in feet.	Section of Metal in Rim of Fly-wheel in square inches.	Number of Teeth in Spur-wheel.	Revolutions of Fly-wheel a minute.
Dowlais, 1	4·3	102	4·6	5·2	21	..	12·0	15·5	144	42	53
„ 2	4·7	102	5·0	4·3	21	..	12·0	16·0	144	33	68
„ 3	5·0	128	4·6	4·9	24	..	12·0	18·0	144	42	61
„ 4	4·7	102	5·0	4·3	21	..	12·0	15·3	144	33	71
„ 5	3·8	96	4·5	..	17	..	8·5	12·0	108	25	114
Hirwain ..	3·0	120	5·0	..	20	3	9·5	16·0	144	26	..
Forest ..	3·0	144	5·0	..	20	3	9·5	16·0	144	26	..

DIMENSIONS OF ENGINES AND MACHINERY AT PUDDLING FORGES—*continued.*

Name of Works.	Number of Trains driven by Engine.	Revolutions of Rolls a minute.	Diameter of Shear-spindles.	Revolutions of Shear-spindle and Cuts of Shears a minute.	Weight of Engine-framing under the level of the Crank-shaft.	Number of Boilers.	Description of Boiler.	Surface of Boiler exposed to the heat of fire.	Area of Fire-grate.	Consumption of Coal every twenty-four hours.	Pressure on Boiler in lbs. a square inch, above atmosphere.
Dowlais, 1	2	53	8	54	46	3	Cylindrical	1200	142	9·5	22
„ 2	2	68	10	22	48	3	„	1134	156	9·5	28
„ 3	2	61	8	41	216	3	„	1100	142	10·0	50
„ 4	2	71	8	59	94	4	„	1296	220	14·0	62
„ 5	2	..	8	57	22	2	„	648	112	8·0	75
Hirwain ..	1	..	..	..	37	..	..	..	200	9·0	7
Forest ..	1	..	..	..	43	..	..	..	..	..	..

Heating or Balling Furnace.—The conversion of the puddle-bars into the various forms of finished iron met with in commerce is effected by heating them in furnaces, commonly called balling furnaces, Figs. 4507 to 4510—but perhaps heating furnaces, the name by which they are distinguished in some works, is more appropriate—and afterwards rolling them out into bars, or plates, of such sections and dimensions as may be desired.

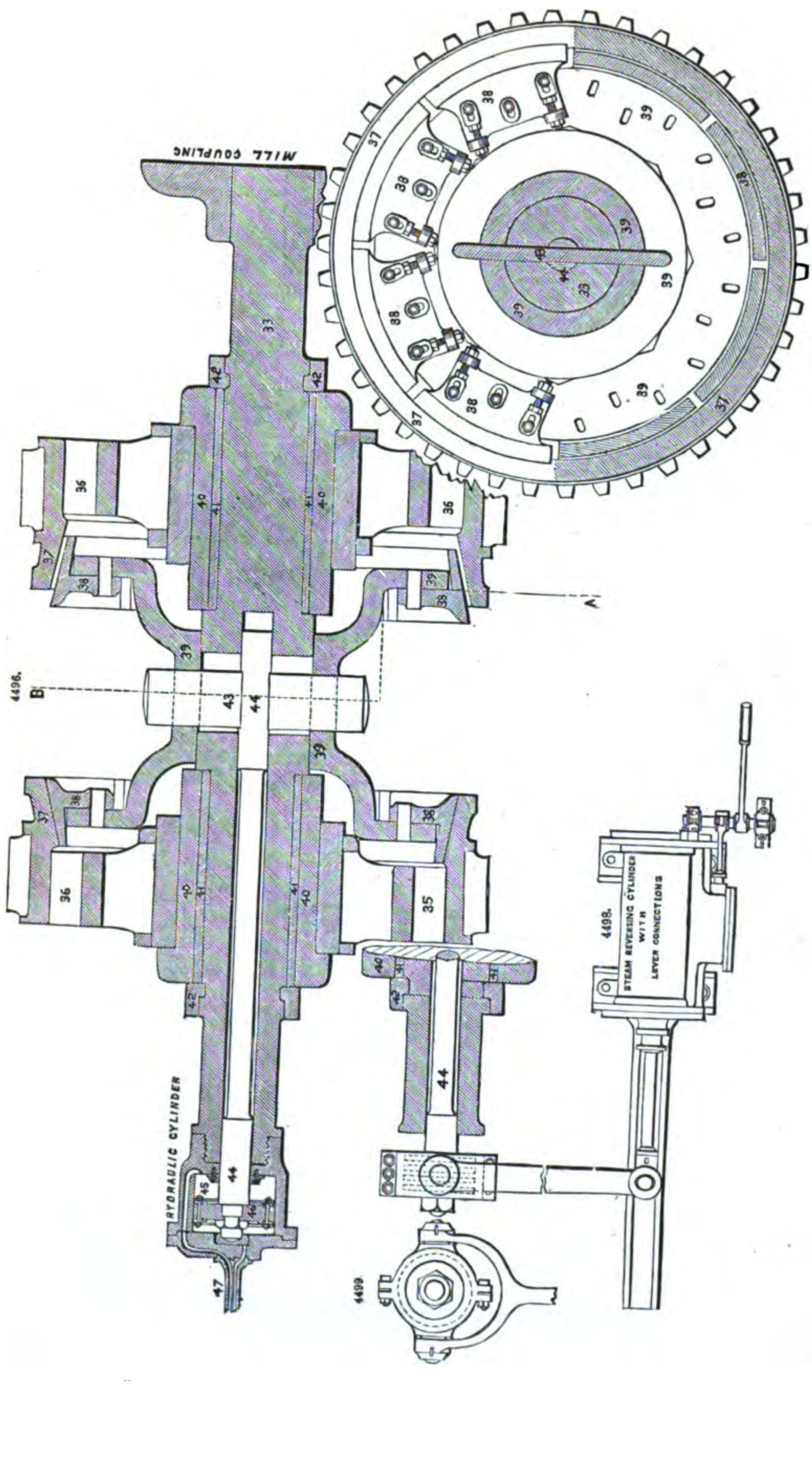
The heating furnace is very similar to the puddling furnace; it has a chimney of like dimensions, but is generally 8 or 9 in. wider and 2 ft. longer, for working the larger sizes of iron. The area of the fire-place averages 12 ft. The cast-iron bottom is placed 13 or 14 in. below the working door, and on it a sand bottom is laid, falling from the door, both towards the back of the furnace and towards the flue. Between the body of the furnace and the fire-place a bridge, 9 in. thick, is carried up to within 14 in. of the roof; and at the stack end the sand bottom is gradually rounded off to meet the floor of the flue. The iron bottom is not indispensable, though generally used. If the bridge be carried up from the bottom of the ash-pit, the inside space may be filled up with any convenient material to a level for the sand bottom. A stock-hole and working door complete the heating furnace.

A number of puddle-bars of a suitable length, generally from 3 to 4½ ft., are placed together to form a *pile*, the sectional dimension of which varies with the size of iron ordered, from 3 in. to 10 in. square. If the piles are made 3 ft. 6 in. long and 7 in. wide, by 8 in. high—a common size for railway bars and the larger kinds of merchant iron—the baller charges four at a time for a heat, by placing them singly on a flat iron bar, called a *peeler*, and sliding them into the furnace, taking due care not to displace the arrangement of the bars. When charged the four piles will lie nearly across the furnace, radiating from the door, the ends towards the back lying 6 or 8 in. lower than those nearest the door.

Figs. 4511, 4512, are views of piling tables, and Fig. 4513 a rest.

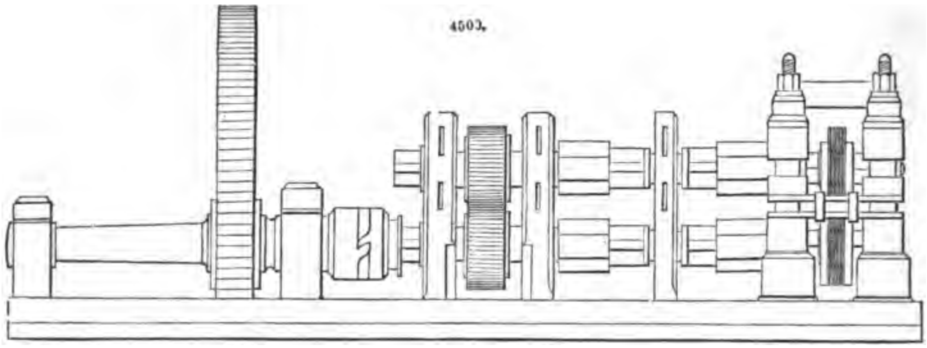
A little fine coal is thrown around the door, to exclude the cold air, and the damper opened to its widest extent. The grate is cleaned, fresh fuel added, and the fire urged to the production of an intense heat. After charging, the baller's chief occupation is watching the piles, and turning them so that they may be heated equally, and be brought to a welding heat in the least time. When this point is approached, a portion of the iron becomes oxidized, and, combining with the earthy matter, it forms a cinder, which flows over the surface of the pile, and protects it for a brief period from the further action of the air. If the operation be prolonged the flow of cinder ceases, and the iron suffers from the oxygen of the air, losing its tenacity and property of welding.

A *heat* such as we have described will be ready in sixty minutes. The piles are then grasped by a pair of heavy tongs, Fig. 4514, and dragged on to a carriage, Figs. 4515 to 4517, for conveyance

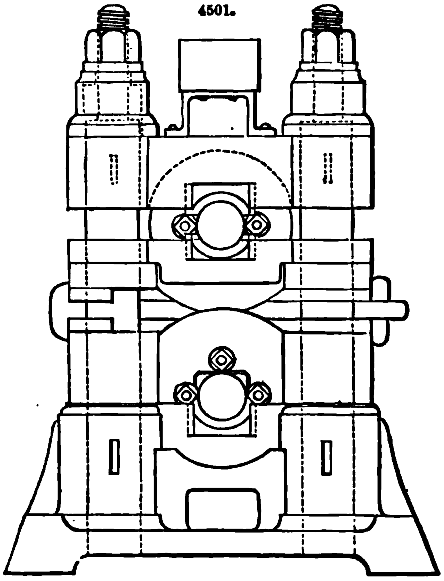


4497. Transverse section on line A B.

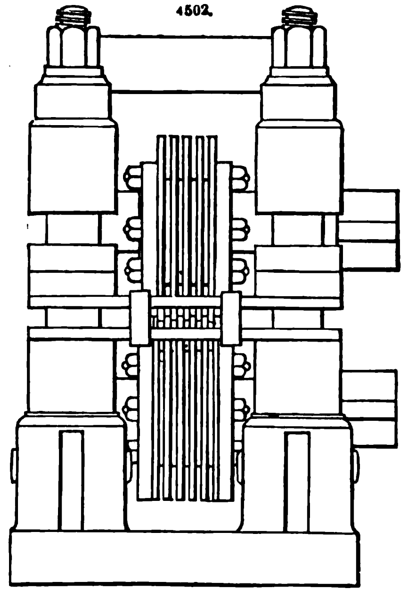
4500.



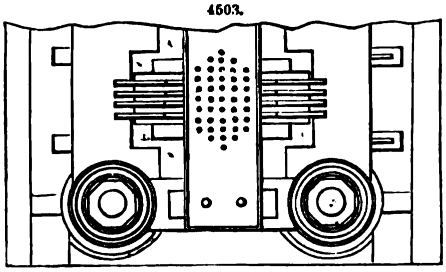
4501.



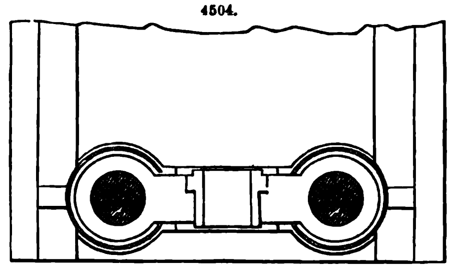
4502.



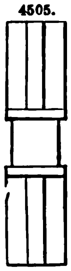
4503.



4504.

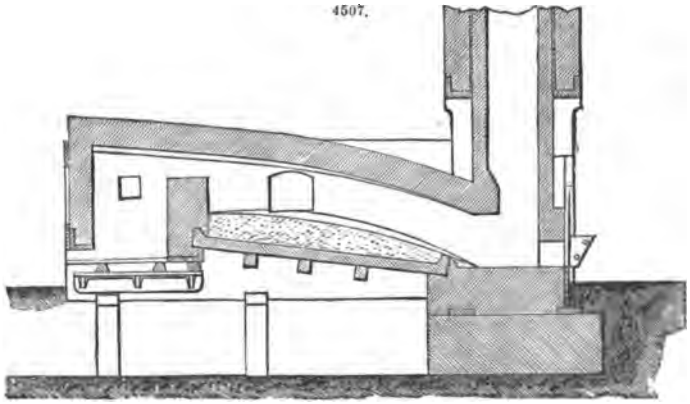


4505.



4506.

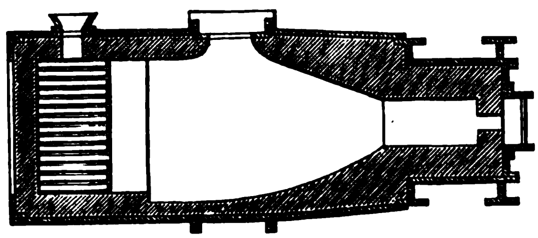
4507.



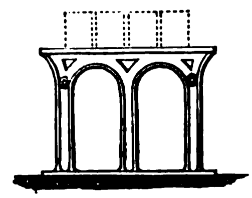
to the rolls. The drawing out, charging a fresh heat, and repairing the bottom, will average sixteen minutes a heat. Piles of this size weigh about 4 cwt. each. At this rate, a heating furnace will work thirty-six piles in the twelve hours, or 83 tons of iron a week.

For the smaller sizes of merchant bars the piles are made about 18 in. long, 3 in. wide, and $2\frac{1}{2}$ to

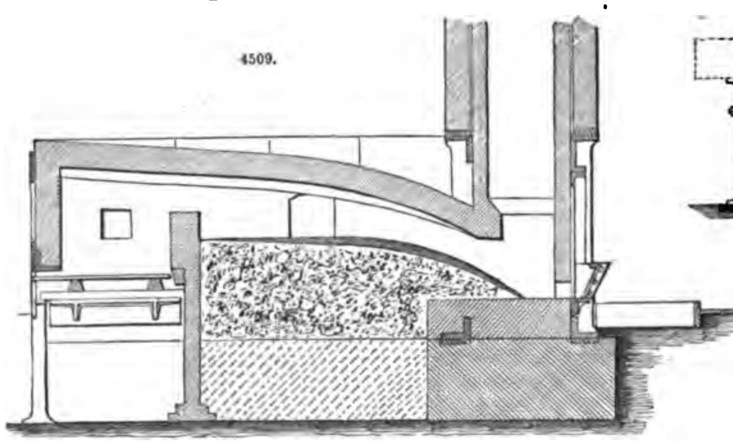
4508.



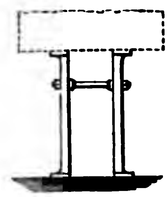
4511.



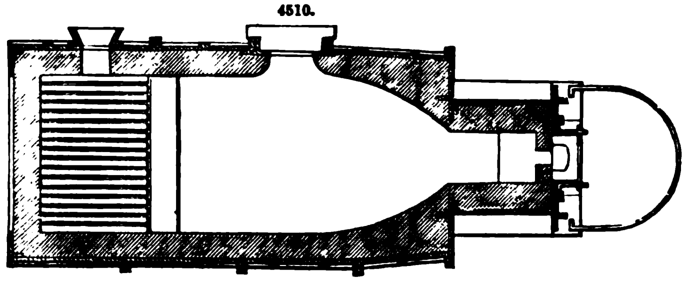
4509.



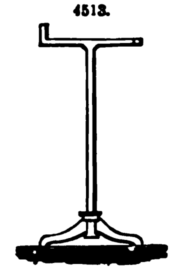
4512.



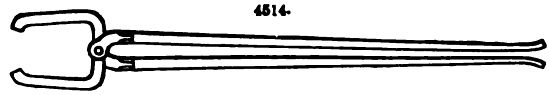
4510.



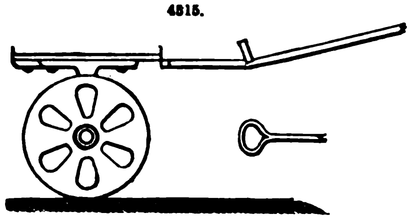
4513.



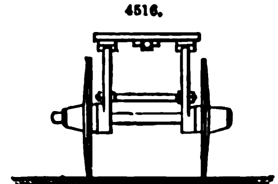
4514.



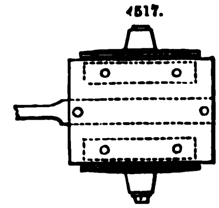
4515.



4516.



4517.



3 in. thick. The heat is composed of sixteen or eighteen piles, which take from twenty-eight to thirty minutes in reaching a welding heat. The time occupied in drawing out the heat, recharging, and repairing, averages twenty-one minutes. A furnace upon piles of such a size working at this rate heats about 31 tons weekly.

The smallest sizes of bars are rolled from solid bolts of manufactured iron, termed *billets*, measuring 12 to 20 in. long by $1\frac{1}{4}$ to $1\frac{3}{8}$ in their diameter. Smaller heating furnaces are employed,

and from twenty-five to thirty billets are heated at once. To economize time and reduce the waste of iron, which otherwise would be very great with the smallest sizes, cold billets are charged nearly as fast as the hot ones are withdrawn. Furnaces working on billets for guide iron heat from 15 to 25 tons a week, according to the size of the finished bar.

The loss of weight during the heating process is dependent chiefly on the skill of the baller. With care and a fair average quality of iron the loss will not exceed 80 lbs. a ton on the large piles, 130 lbs. on the smaller sizes, and 210 lbs. on the guide-rolled iron. The yield or consumption of puddle-iron to produce one ton of finished iron is ordinarily much greater than this, but having accurately weighed the iron before and after heating, we find that perfectly sound bars may be produced with a loss no greater than that we have stated.

The consumption of coal in heating the large-size piles averages 7 cwt. to the ton of iron charged; in the smaller sizes, 10 cwt.; and in the smallest merchant bars, 13 cwt.

The formation of the pile, in the arrangement of the pieces, their size, weight, and quality, is a subject of much importance in the manufacture of sound bar-iron. The form of the finished bar, and the purpose to which it is to be applied, require to be carefully attended to in the piling, together with the local character of the iron about to be employed.

A rail pile for the common qualities of rails is usually composed of a bottom piece of No. 2 iron 6 or 7 in. wide by 1 in. thick, on which eighteen or twenty pieces of puddle-iron 3 to 3½ wide by ¾ thick are placed, capped by a second piece of No. 2 iron of the same size as the first. If intended for flanch rails, square bars of soft iron are added to the plate of No. 2 to form the flange. The iron for these bars is worked for the purpose from a burden containing little or no red ore or refinery cinder. Thin and broad flanged rails cannot be worked unless attention is paid in the piling to ensure the presence of a very soft tenacious iron in the flange. The greater diameter of the rolls at the body of the rail dragging the thin portion through, throws a strain upon the flanges in the finishing grooves sufficiently great sometimes to tear them off. In heating, also, care is required that the pieces to form the flange are not overheated.

If the rail is large, or the metal unequally distributed, the process of shaping is frequently commenced in the pile, which is made of a diminished width at the head.

For the double-headed, the bridge, and some other varieties of railway iron, a common pile is made, such a proportion of superior iron being used as the specification requires or the manufacturer deems necessary. A portion of the centre is frequently made with pieces of rails cut into short lengths for remanufacture. From their irregular section, however, they do not work in well with flat bars; and to render the pile more solid, puddle-bars are rolled of such a form as will, when combined with the rails, leave the smallest interstices.

In the manufacture of merchant iron of No. 2, or common quality, the pile is composed entirely of puddle-bars laid one on the other. For larger piles, and where the width greatly exceeds the height, a double row of bars is employed; in all cases the pile is rectangular.

The piles for No. 3 iron are made in the same manner, but with No. 2 iron instead of puddle-bars. The superiority of No. 3 to No. 2 is consequently due to the additional reheating and rolling, by which the fibre and general quality of some irons are considerably improved.

In the manufacture of particular varieties, in order to develop the fibre as much as possible, the pile is made short and thick, so that in the subsequent great elongation by rolling the iron may become of a dense fibrous character. For this purpose the short thick pile is evidently superior to any other form, but in consequence of its requiring a longer time to heat, the outside gets burnt before the interior is brought to a welding heat; the manufactured iron consequently is not equal to that produced with a larger pile—it is rarely sound in the centre, and its tensile strength, if tested, will be found to have suffered by the overheating of the external parts.

In the manufacture of large bolts, the pile is sometimes made of a number of bars of a wedge-like section arranged radially around a central bar, forming a cylinder, kept together by thin iron bands. This is heated in the balling furnace and rolled into a bolt of the desired diameter and length. By some mechanical engineers this mode of piling is supposed to ensure a more solid bolt than the ordinary rectangular pile of flat bars. In practice, however, it is found difficult to produce a sound bar from a pile of this kind. Since the centre bar can only receive its heat by conduction from the radial bars, it cannot reach a welding heat till long after the outer parts, and the pile is generally drawn before the centre has arrived at a proper temperature. The result is, that in passing through the rolls the radial bars are firmly welded to each other at their circumference, but very rarely throughout their entire depth; the central bar is elongated with the rest, but is not welded to them.

In piling, care should be taken to have the various pieces forming the pile of the same thickness as nearly as may be practicable. If they differ greatly, both the risk of unsoundness and the loss of iron during the heating will be increased. The thinnest pieces are hot first, and if the pile is drawn at once the weld with the thick bars is rarely sound. On the other hand, if the pile is retained in the furnace until the thick pieces are properly heated, the thinner are overheated, deprived of the protecting cinder, and weld with difficulty. Sufficient attention is seldom paid to this point in the manufacture of railway and other bars.

It has been found that to heat a pile 6 in. thick, composed of two widths and ten thicknesses of puddle-iron, 3 in. by ¾ in., in an ordinary balling furnace, so that the whole was brought to a welding heat, required on an average fifty-two minutes. It has been further ascertained that to heat a pile of a single width of puddle-bars in the same furnace, and exposed to a similar temperature, required twenty-seven minutes, and smaller sizes in the same proportion. By these and other experiments, Truran concluded that the time required for heating a pile or mass of iron was nearly in the same ratio as its thickness. Hence the necessity for building the pile of pieces of the same thickness. In a smith's fire, the difference in the thickness of pieces of iron to be welded together is allowed for by partially heating the thicker piece before the other is charged, a mode of working inapplicable to the rapid rate of execution practised in rolling mills.

For some kinds of iron faggoted piles are employed; these are formed in different ways, often by making a box pile of iron plates, and filling the interior with clippings of plates, old chains, or other scraps. They are heated and then rolled, or, what is preferable, hammered well under a heavy hammer, and reheated before being rolled. Hammering improves the quality of scrap-iron.

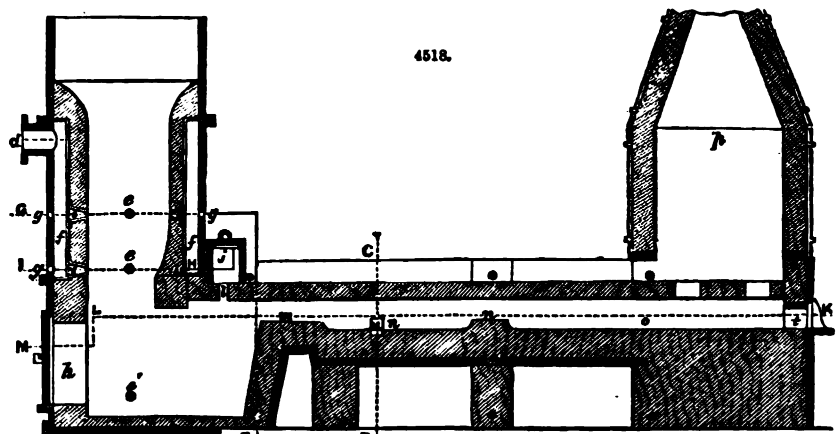
Angle-iron, tramplates, and T-iron are usually rolled from piles having a portion of the puddle-bars, or No. 2 iron if for best qualities, cut into short lengths, and laid across the pile. If for angle-iron the top and bottom pieces are laid longitudinally, and the centre of the pile built of layers of transverse and longitudinal bars alternately. The power of the iron to resist a lateral strain is increased by cross-piling, and its structure is rendered more homogeneous.

Bars for manufacture into tin plates are required to be of good quality, seldom under best cable; the piles are usually made as for ordinary bars, but some manufacturers require them to be built with layers of bars laid crosswise. Plate-iron which is to be manufactured into hollow ware and Birmingham goods, known by the rollers as *blackplate*, is piled in a similar manner. Large quantities of tinned iron plates have been made from rail ends and mill crops, but such plates cannot be moulded into the more intricate forms of tinware.

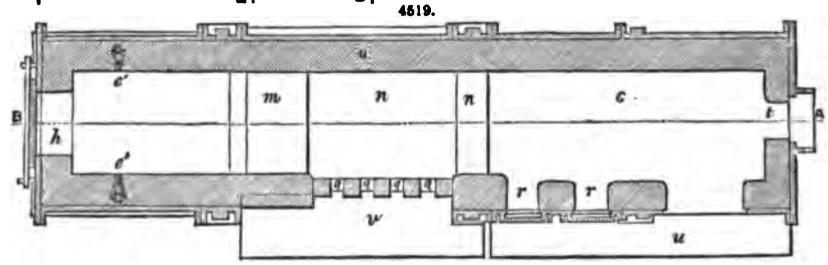
Boiler-plates, if manufactured of best iron, were at one time invariably rolled from piles having alternate layers laid crosswise. A cheaper method is extensively adopted. it consists in hammering two blooms together and rolling them direct into a plate. As the blooms are void of fibre, the extension in both directions in rolling results in the production of a plate equally strong in either direction. The quality, however, is no higher than No. 2 iron. For boiler-plate, it is impossible to exercise too much care in the selection of the crude iron, as well as in the subsequent stages of the manufacture.

Ekman's Reheating Furnace, Figs. 4518 to 4522.—Ekman's furnace is a very useful appliance where

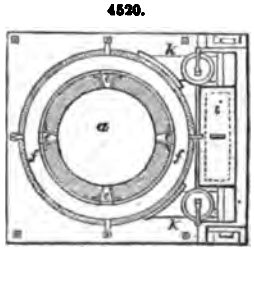
4518.



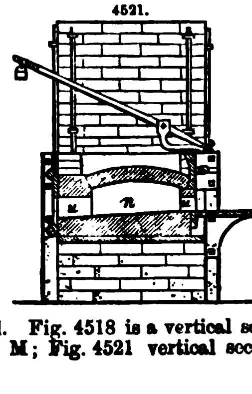
4519.



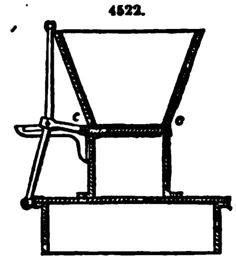
4520.



4521.



4522.



wood charcoal is the fuel employed. Fig. 4518 is a vertical section on the line A B; Fig. 4519, horizontal section on the line K L M; Fig. 4521 vertical section on the line C D; *a* is the gas-

chamber, built of fire-brick, and enclosed within a jacket of cast iron, a free space *f f* being left between the two. In the wall of this chamber are two rows of tuyeres, the upper containing four and the lower three. In the iron jacket is a pipe *d*, through which cold air at a pressure of about 1 in. of mercury is introduced into the space *f f*, the blast in its passage through this space becoming heated to from 90° to 150° C. In the iron jacket, opposite the tuyeres, are corresponding holes *g g*, fitted with movable plugs. On the top of the gas-chamber is fixed a hopper *b*, shown separate Fig. 4522, having a sliding bottom *c c*, through which fuel is supplied, and near the bottom of the chamber are two tuyeres *e' e'*, one on each side. The gas-chamber communicates with the body of the furnace at *m*. In the roof of the furnace, on the right of the fire-bridge, is a series of openings *l l*, connected above with an iron box *i* having an easily movable lid, and communicating with the free space *f f* by two iron pipes *k k* provided with stop-cocks. By this arrangement the air entering through the pipe *d* passes in part into the interior of the gas-chamber and in part into the box *i*, from which it descends through the openings *l l*. When the gas-chamber is filled with ignited fuel, and air is injected through the pipe *d*, carbonic oxide is copiously produced, which in its way towards the fire-bridge *m* is met by currents of heated air from the openings *l l*, and is thus effectually burnt. The iron is heated in the welding chamber included between the fire-bridge *m* and the opposite bridge *n*, and is introduced through the doors *g g*. The heat here is intense. When hot blast is used, the flame scarcely extends beyond the bridge *n*, so complete and rapid is the combustion of the gas. Beyond the welding chamber is a second chamber *o*, where the iron is subjected to a preliminary heating before its introduction into the former; it has two doors *r r* at the side, and a third *t* at the end. In the lower part of the neck *p* any convenient apparatus for heating the blast may be placed. In front of the doors *g g*, *r r* are cast-iron plates for convenience of manipulation. The tap-hole through which the cinder flows is shown at *u*.

With respect to the power absorbed in the different operations of iron manufacturing, in the course of experiments having for their object the economical application of power in iron-works, Truran ascertained that the amount absorbed in the various operations was nearly as follows;—

Smelting Lean Argillaceous Ores.—For compressing the blast to a density of 3 lbs. on the square inch, 55 horse-power to 100 tons of iron smelted weekly, or, allowing for friction and leakage in the engine, 66 horse-power. The horse-power being 33,000 lbs. lifted 1 ft. high a minute.

Smelting Carbonaceous Ores.—For compressing the blast to a density of 3 lbs., 22 horse-power to 100 tons smelted weekly, equal to 27 horse-power, including friction and unavoidable loss.

Refinery.—For compressing the blast to a density of 2¼ lbs. to the square inch, for refining forge iron in the running-in fire, 13 horse-power for every 100 tons refined weekly, equal to 16 horse-power, including friction and waste.

Puddling Forge.—No. 1. For driving a puddling train, consisting of a pair of 18-in. finishing rolls, a pair of roughing rolls, a double-ended squeezer, and two pairs of cropping shears at 55 revolutions a minute, rolling bars 3 in. by ⅝ in., puddled from refined metal. Power expended in keeping the trains and machinery in motion, 41 horse-power. Additional power, when in full work, rolling and squeezing at the rate of 300 tons weekly, representing the mean force exerted in shaping the iron, 34 horse-power. Total power absorbed, 75 horse.

No. 2. For driving puddling train, with rolls and squeezer similar to the above, but running at 82 revolutions a minute, and rolling bars 3 in. by ⅝ in. from boiled pigs. Power absorbed by the engine and machinery, 17·5 horse-power. By the roll train running light, 28·5 horse-power. Total power absorbed by engine, machinery, rolls, and squeezer running light, 46 horse-power. Additional power absorbed when rolling and squeezing at the rate of 360 tons weekly, representing the force expended in shaping the iron, 67·5 horse. Total power expended, 113·5 horse-power.

Rolling Mill.—No. 1. For driving rail train, consisting of a pair of 18-in. roughing rolls, a pair of finishing rolls, and intermediate pinions worked by a horizontal high-pressure engine, with cropping shears, eight straightening presses, and saws in connection—the speed of rolls being 85 revolutions a minute, and rolling T-rails. Power absorbed in driving engine, rolls, and all the machinery light, 71 horse-power. Additional power absorbed when rolling, 168 horse-power. Total power driving rail train, capable of making 600 tons of rails weekly, 239 horse-power.

No. 2. For driving 18-in. bar train, consisting of a pair of roughing rolls, a pair of finishing rolls, and cropping shears. Power absorbed by the engine and machinery for three such trains when running light, including power absorbed in driving four rail presses and pair of saws, 52 horse-power. Power absorbed by each train of rolls when running light, 21 horse-power. Additional power absorbed by trains respectively, when rolling 1½-in. bolts, 29·5 horse-power; when rolling 1½-in. squares, 29·5 horse-power; when rolling 4 in. by 1 in. flats, 102 horse-power. Gross power consumed in driving the three trains and machinery loaded, 276 horse-power. Total power, including engine and machinery, absorbed by train of bar rolls rolling flats, 149 horse-power.

No. 3. For driving 12-in. bar mill, a pair of roughing and a pair of finishing rolls, with engine and machinery, at 140 revolutions a minute, light, 26 horse-power. When rolling bolts and squares additional, 23 horse-power.

No. 4. For driving 12-in. train, consisting of a pair of roughing and a pair of finishing rolls, driven at 110 revolutions a minute by independent engine, rolling flats 1½ in. by ½ in., 32 horse-power.

No. 5. For driving a train of 8-in. merchant bar rolls, consisting of three roughing, three ovals, and a pair of finishing rolls, working at the rate of 220 revolutions a minute. Power expended in maintaining engine and machinery in motion, 17 horse-power. Power absorbed in running train, light, 24 horse-power. Additional power when rolling ⅜-in. flats, 21 horse-power; when rolling ½-in. flats, 14 horse-power. Gross power expended when rolling ½-in. flats, 55 horse-power.

No. 6. For driving 8-in. train similar to the above, with separate engine and machinery, when rolling squares and bolts, 61 horse-power.

No. 7. Power absorbed in driving a pair of rail saws, 4 ft. 6 in. diameter, 820 revolutions a minute, 11 horse-power.

See ATOMIC WEIGHTS. BLAST FURNACE. COAL-WASHING MACHINE. DISTILLING APPARATUS, page 1219. FORGING, *Machinery for.* FURNACE. ORES, *Machinery and Processes employed to Dress.* OVENS. PYROMETER. STEAM-HAMMER. STEEL. TUYERE.

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IRON SHIPBUILDING. FR., *Construction des Navires en fer;* GER., *Kunst des Baues der eisernen Schiffe;* ITAL., *Costruzione delle navi di ferro;* SPAN., *Construccion de buques de hierro.*

The extended and increasing use of iron ships at the present day, after the lapse of about forty years since they were first fairly introduced, renders their construction a subject of importance to the engineer, as well as the naval architect: for the application of iron in place of wood to the structure of ships has necessitated a more careful use of the material employed, and a more correct and perfect application of the mechanical principles that are involved in the construction. It is not intended in the present article to describe novelties of construction in iron ships, so much as to investigate certain systems that are approved and practised.

John Vernon, of Liverpool, in a paper on the construction of iron ships in the Trans. I. M. E., justly remarks that the main points of superiority of iron ships over those built of wood consist in the superior strength, greater durability, and less cost of iron ships, together with their larger carrying capability, greater facility of construction, and the more certain supply of the material.

The greater strength of iron ships is shown in daily practice in numerous ways; and it is also shown by the fact that in many modern wood ships it has been found desirable to introduce the use of iron for bulkheads, beams and stringers, and even for the framework itself of the whole structure. But this arrangement it is considered falls very far short in point of strength of a vessel built entirely of iron; and the only ground upon which such a mixed kind of structure can be advocated is the freedom from fouling possessed by wood vessels when they are coppered, which is an advantage existing in the mixed structure on account of the shell portion being of wood.

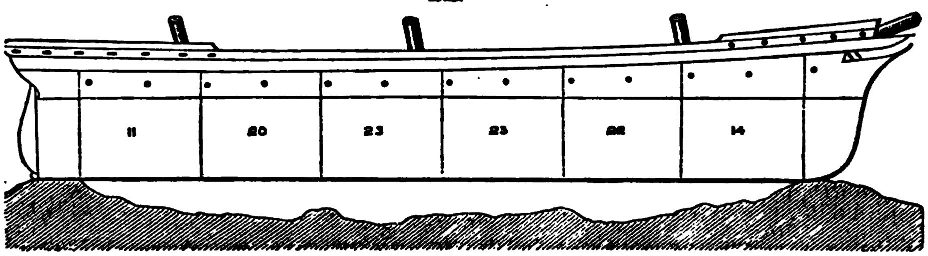
The greater comparative durability of iron for the construction of ships arises mainly from its freedom from the decay to which wood is always liable in consequence of its being unavoidably subject to constant and extreme variations of temperature and moisture. Another important source of this greater durability is to be found in the firm and substantial union of the several parts of an iron ship by means of riveting, which effectually prevents that *working* under heavy strains to which all wood ships are more or less liable.

The larger carrying capability of the iron ship arises first from the reduced weight of the structure, and secondly from the increased internal capacity with the same external dimensions and model as the wood ship. This is shown by the following figures of comparison of a 1200-ton ship of the two constructions. First as to weight. The wood ship with rigging and all outfit weighs say 18 cwt. a ton measure, equal to 1080 tons for the whole ship. The iron ship completed in a similar way weighs only say 15 cwt. a ton measure, which would be equal to 900 tons for the whole ship. Hence the 1200-ton iron ship will carry at the same draught 180 tons additional dead weight of cargo; and this will be equal to 11 per cent. addition upon the whole weight of 1600 tons which is actually carried by a nominal 1200-ton wood ship; or if no greater weight be carried, the iron vessel will float at 13 in. less draught of water. Secondly as to capacity. The wood ship has an internal capacity of 93,343 cub. ft., or, at 100 ft. a ton, 933 tons. The iron ship, because of the reduced thickness of the sides and bottom of the hull, has a capacity of 1108 tons. Hence in regard to capacity the gain of the iron ship is 175 tons, or about 19 per cent. over the wood ship; and there will consequently be space enough to contain the increased weight of 11 per cent. which the iron ship is capable of carrying by reason of its lighter hull.

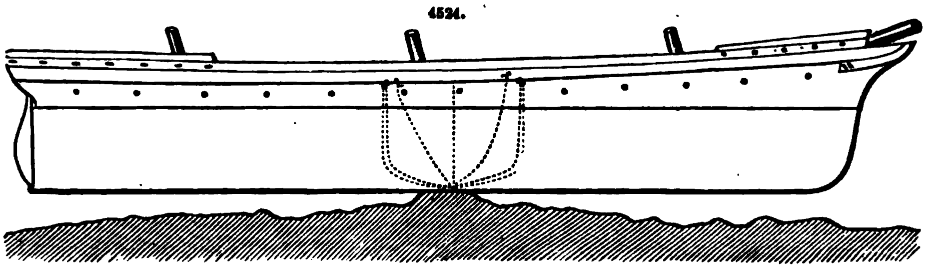
With respect to the actual strength of an iron ship, its capability of bearing strain, and whether the distribution of material is judicious and efficient, considering the strains to which it is

subjected, the case will be taken of a ship of 1200 tons, as shown in side elevation, in Figs. 4523, 4524, the dimensions of which are 205 ft. length, 34½ ft. beam, and 23 ft. depth of hold; and the

4523.



4524.



ship is supposed to be built to class A 1 at Lloyd's for twelve years, or for twenty years with the Liverpool Underwriters' Association. The transverse section of such a ship is shown to a larger scale in Fig. 4525, the section of the iron being shown black; and the sectional area of iron is as follows;—

		Sq. Ins.
Stringer-plates, tie-plates, and angle-irons on main deck ..	A	77
" " " on lower deck ..	B	55
Sheerstrakes	C	61
Sides down to top of bilge	D	298
Turn of bilges and flat of bottom	E	379
Garboard strakes	F	59
Middle keelson	G	42
Sister keelsons	H	43
Bilge keelsons	I	20
Lower hold stringers	K	41
Keel-piece	L	26
Total		1101

In the above sectional area the deck planks, amounting to 1770 sq. in., have been excluded from the calculation, because although aiding considerably when in compression they are of very little value for tension; and both cases have to be taken into account.

Taking first the extreme case of strain upon the vessel when supported only at the ends, and allowing 10 ft. length at each end for the support, the ship will be as shown in the diagram, Fig. 4523, with a length of 185 ft. between the supports; in this case the bottom of the vessel is in tension and the top in compression. The displacement of such a vessel at her loaded draught of 20 ft. is 2703 tons, and this weight is made up as follows;—

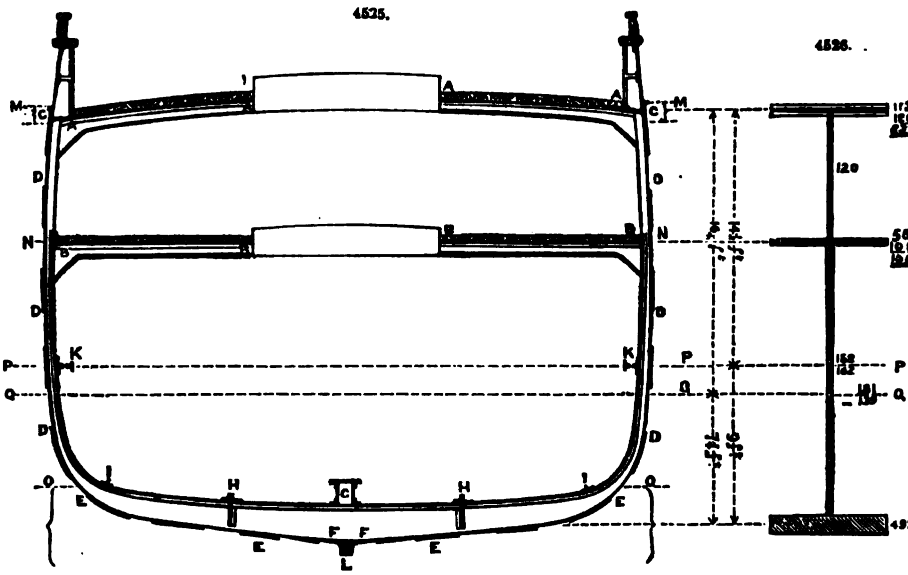
		Tons.
Iron in hull for 1166 tons measurement, at 10½ cwt. a ton ..	612	758
Woodwork " " at 2½ cwt. a ton ..	146	
Rigging and outfit	108	1945
Water and general stores	35	
Weight of cargo	1802	
Total		2703

The cargo and other load carried is thus seen to amount to 1945 tons, which load is unequally distributed over the length of the ship in consequence of the larger capacity in the midships as compared with that at the two ends; and the proportionate distribution as measured from actual sections of an existing ship is shown approximately by the figures marked upon the side elevation, Fig. 4523. The length unsupported being divided into six equal portions, the respective cargo capacities or loads of these are in the proportions of 11, 20, 23, 23, 22, 14 respectively, proceeding from the stern to the bows. The result obtained by taking the mean effect of these several loads at the centre of the vessel is that the strain produced at the centre by the distributed load

amounts in this case to 74 per cent. of the total load, instead of 50 per cent. or one-half the load as would have been the case if the distribution of the load had been uniform throughout the entire length. Hence the total distributed load carried being 1945 tons, as ascertained above, the equivalent centre load will be in this case 74 per cent. of that amount, or 1440 tons; and the additional weight of the vessel itself, 758 tons, may be considered as equivalent to a load of one-half the amount, or 379 tons at the centre; making together a total load at the centre of 1819 tons, one-half of which, or 909 tons, is acting at each end by tension on the lower part of the vessel, with a leverage of 92½ ft., or half the length of the unsupported portion of the vessel.

As the form in which the material is placed in the sectional area of the ship is necessarily determined by the carrying and floating requirements of the ship, and is consequently not free to be arranged in the manner that would simply give the greatest strength as a girder, this case does not admit of satisfactory comparison with a wrought-iron box-girder for calculation of the transverse strength. It may be convenient consequently to consider the strains on the whole sectional area as if acting upon a solid girder composed of the material that exists at each point in the depth of the vessel, concentrated into a solid girder of the same sectional area and depth. The diagram, Fig. 4526, shows the total sectional area of the vessel drawn to double the scale of Fig. 4525 in area, or $\frac{1}{1000}$ of the actual area of section. The metal is here condensed into the form of a flanged girder for comparison of the areas of resistance in the several portions, in order to deduce an approximate neutral axis for the whole section; and the positions of the several portions of the girder are made to correspond with the exact positions in the general section of the vessel itself, Fig. 4525. The sectional areas of iron at the main deck, lower deck, and bottom,

4525. 4526.



are 113, 55, and 493 sq. in. respectively. The top flange of 113 sq. in. area is made up of the main deck plates and angle-irons A of 77 sq. in., and 36 sq. in. of the sheerstrakes C from the top M downwards; the bottom flange is taken to include the entire section of iron in the bottom E E of the vessel, from the keel L up to the points O O at turn of bilge on either side, together with the five keelsons G, H H, and I I. The intermediate areas of the sides are 120 sq. in. between the upper and lower decks, from the sheerstrakes C down to the lower deck N; and 320 sq. in. from the lower deck N down to the point O, at which the bottom is considered to begin; the latter area being divided into two portions of 158 and 162 sq. in. respectively above and below the neutral axis P P. Then these several areas multiplied into their respective vertical distances or leverages give the upper dotted line P P as the approximate neutral axis, about which the moments of the areas above and below are equal; taking the total compression resistance of the upper portion as ⅘ of the tensile resistance of the lower portion, since the ultimate strength a square inch of wrought iron to resist compression is ⅘ of its strength for tension.

In this case the decks being in compression, and the 4 and 3 in. planks of which they are composed being fixed tight and solid together, the timber will contribute materially to the strength of the ship. The resistance of the pinewood to compression may be taken at 3 tons a square inch: and the compression strength of wrought iron being 17 tons a square inch, or ⅘ of its tensile strength of 20 tons, the strength of the wood is about ⅙ that of wrought iron; the value of the timber may therefore be safely taken at ⅛ of the strength of wrought iron a square inch. Hence the sectional area of the main deck planking being 960 sq. in., ⅛ of this, or 120 sq. in., has been added in the above calculation to the area of the top flange of the girder in Fig. 4526, as shown by the outer lines surrounding the shaded portion, making the total area of the top flange 233 sq. in. For the lower deck of 810 sq. in. sectional area, ⅛ of this, or 101 sq. in., has similarly been added, making a total area of 156 sq. in.

The neutral axis P P thus found is situated 9 ft. above the centre line of the bottom portion,

Figs. 4525, 4526; and the strain tending to produce fracture at the centre of the vessel will therefore be 909 tons × 92½ ÷ 9 = 9343 tons. Then, assuming this strain to be resisted by all the portions in tension in proportion to their respective distances from the neutral axis P, the effective area resisting by tension will be 493 sq. in. for the bottom portion, and ⅓ of 162, or 54 sq. in., for the lower sides, since the centre of gravity of the lower sides, from the neutral axis P down to the point O in Fig. 4525, is only a little more than one-third of the way down from the neutral axis P to the centre line of the bottom portion, as seen in Fig. 4525. Hence the total effective area-resisting tension is 547 sq. in., on which the above load of 9343 tons gives a strain of 17 tons a square inch upon the iron.

This calculation is on the extreme supposition of the vessel being entirely out of the water, and supported only at the two extremities; but practically the vessel, when carrying her cargo, is supported from end to end by the water, excepting to the extent that this support may be partially withdrawn by the waves and other causes, producing an inequality of immersion. It has to be observed that, although the weight of the whole vessel is balanced by its displacement, the extreme ends are very much heavier than their own displacements, and consequently a larger weight is left unsupported at the ends; and the effect of this imperfect support of the ends of the vessel while afloat, inasmuch as it throws a strain of compression on the bottom, will to that extent reduce the strain of tension to which the bottom of the vessel is exposed in the case under consideration, when she is supported at the ends only.

Considering the opposite case of the vessel being supported only at the centre, as in Fig. 4524, the strains on the vessel will then be reversed: the top will be in tension and the bottom in compression. In this case the effect of the unequal distribution of the load, taken from the same data as before, will be to produce a strain corresponding to a load at the ends of the vessel amounting to only 44 per cent. of the total load, instead of 50 per cent., or one-half, as would have been the case if the load had been uniformly distributed throughout the entire length. The total distributed load carried being 1945 tons, as before, the equivalent load at the ends will in this case be 44 per cent. of that amount, or 856 tons, acting at the two ends; and the additional weight of the vessel itself—758 tons—being taken, as before, to be equivalent to one-half that amount, or 379 tons at the two ends, these make together a total load at the two ends of 1235 tons, one-half of which or 617 tons, is acting at each end by tension on the upper part of the vessel, with a leverage of half the unsupported length of the vessel, or 92½ ft., as before.

The neutral axis in this case, found in the same manner as before, but omitting from the calculation the sectional area of the decks which are now in tension, is shown by the lower dotted line Q Q, Figs. 4525, 4526; it is situated at a depth of 16¼ ft. below the centre of the upper portion, or 21 in. below the previous neutral axis P, thus dividing afresh the 320 sq. in. area of the lower sides from N to O, Fig. 4525, into two portions of 181 and 139 sq. in. respectively above and below the neutral axis Q, as seen in Fig. 4526. The strain tending to produce fracture at the centre of the vessel will therefore be 617 tons × 92½ ÷ 16¼ = 3512 tons. Then the effective area resisting by tension, found in the same manner as before, will be 113 sq. in. for the main deck portion, together with ¾ of 120, or 90 sq. in., for the top sides between the decks, ½ of 55, or 27 sq. in., for the lower deck portion, and ¼ of 181, or 45 sq. in., for the sides below the lower deck; making a total effective area of 275 sq. in. resisting by tension. Hence the strain produced by the above load of 3512 tons will be 13 tons a square inch upon the iron.

It may be observed that, although this is an extreme case, it is by no means imaginary as regards the strain which a vessel has to bear continually when floating in the water. For the effect of the imperfect support of the ends of the vessel while afloat, which was previously referred to, is to cause a strain on the transverse area of the midship section similar in action to that caused by the vessel being supported in the middle alone, entirely out of the water, and differing only in degree.

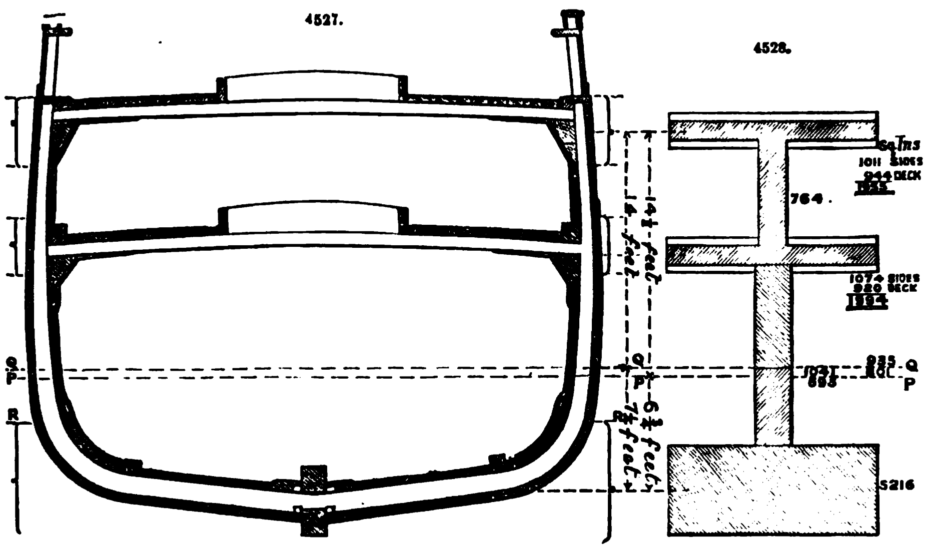
In order to ascertain the comparative strength of iron and wood ships under the two extreme conditions of strain, the same calculation will now be applied to a wood ship of the first class of the same size—1200 tons—of which a transverse midship section is shown in Fig. 4527, to the same scale as the section of the iron ship in Fig. 4525. In Fig. 4528 is shown as before, condensed into the form of a solid girder, the area of section of the wood ship, drawn to double the scale in area of Fig. 4527, or $\frac{1}{1000}$ of the actual area of section. The bottom flange of the girder, Fig. 4528, is taken to include all the section of material in the bottom of the vessel, from the keel up to the points R R on either side in Fig. 4527. The actual areas of each portion of the section are as marked upon the drawing, Fig. 4528, namely, 1011 and 1074 sq. in. in the main deck and lower deck portions respectively, exclusive of the decks themselves; 764 sq. in. in the sides between the upper and lower decks; 1736 sq. in. in the lower sides from the lower deck down to the point R, where the bottom is considered to begin; and 5216 sq. in. in the bottom. In these areas the ceiling or lining of the hold, being constructed of 4-in. planking secured to the frames of the ship, has been included as acting efficiently both in compression and tension.

When the vessel is supported only at the ends, having the bottom in tension, the main and lower decks, of 944 and 920 sq. in. area respectively, have to be included in the compression resistance, as in the iron ship; thus the areas of the main and lower deck portions are here increased to 1955 and 1994 sq. in. respectively, as shown by the outer lines surrounding the shaded portion in Fig. 4528. The neutral axis in this case is shown by the lower dotted line P P; it is obtained in the same manner as before in the iron ship, by multiplying the several portions of the section, Fig. 4528, into their respective leverages or vertical distances from the line P P, so as to make the moments equal above and below that line; the only difference for the wood ship is that here the ultimate resistance of the timber to compression is taken as three-fourths of its resistance to tension. This gives the neutral axis P at 6¾ ft. above the centre line of the bottom flange of the girder in Fig. 4528, dividing the lower sides into two portions of 1041 and 695 sq. in. respectively above and below the neutral axis.

The weight of the 1200-ton wood vessel without cargo is 18 cwt. a ton measure, or 1080 tons

total, as previously stated. Deducting 143 tons for the weight of the rigging, outfit, water, and stores, the same as in the iron vessel, the weight of the hull is 937 tons; half of which, or 468 tons, is therefore taken at the equivalent load at the centre. The internal capacity of the wood ship having been already stated to be only 933 tons as compared with 1108 tons capacity of the iron ship, the total distributed load of 1945 tons carried by the iron ship will be reduced in the same proportion, amounting to 1638 tons; and the equivalent centre load being 74 per cent. of the distributed load, as before, amounts in this case to 1212 tons. The total centre load is therefore 1680 tons, or 840 tons at each end of the ship, with a leverage of half the unsupported length of the vessel, or 92½ ft.

Hence the strain tending to produce fracture at the centre of the vessel will be 840 tons × 92½ ÷ 6¾ = 11511 tons tension upon the portions of the section below the neutral axis, Fig. 4528. The effective area resisting this strain is 5216 sq. in. for the bottom portion, and ¼ of 695, or 174 sq. in., for the sides below the neutral axis, since the centre of gravity of the sides, from the neutral axis P down to the point R in Fig. 4527, is only one-fourth of the way down from the neutral axis P to



the centre line of the bottom portion, as seen in Fig. 4527. The total effective area-resisting tension is therefore 5390 sq. in., on which the above load of 11,511 tons produces a strain of 2⅛ tons a square inch.

In the opposite case of the vessel supported only at the centre, the top is in tension, and the decks are therefore not included in the resistance. The neutral axis, found as before, is shown by the upper dotted line Q Q, Figs. 4527, 4528, which is situated 14 ft. below the centre line of the upper portion, Fig. 4228, 6 in. above the previous neutral axis P; thus dividing afresh the 1736 sq. in. area of the lower sides into two portions of 935 and 801 sq. in. respectively above and below the neutral axis Q, as in Fig. 4528. The weight of the hull—937 tons—is equivalent to half that amount, or 468 tons at the two ends; while the distributed load of 1638 tons in the wood ship is equivalent to 44 per cent. of that amount, or 721 tons at the two ends. Hence the total load at the two ends is 1189 tons, one-half of which, or 594 tons, is acting at each end by tension on the upper part of the vessel, at the leverage of 92½ ft. as before.

The strain tending to produce fracture at the centre of the vessel is therefore 594 tons × 92½ ÷ 14 = 3925 tons tension upon the portions of the section above the neutral axis Q, Fig. 4528. The effective area to resist this strain is 1011 sq. in. for the main deck portion, together with ¾ of 764, or 573 sq. in., for the top sides between the decks, ⅜ of 1074, or 403 sq. in., for the lower deck portion, and ⅐ of 935, or 134 sq. in., for the sides below the lower deck. This gives a total effective area of 2121 sq. in. resisting by tension, upon which the above load of 3925 tons produces a strain of 1⅞ ton a square inch.

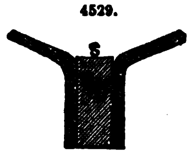
Thus if the average tensile strength of all the wood employed in the longitudinal timbers and decks of the ship, namely, teak, greenheart, elm, and pine, be taken at 6 tons a square inch in the solid material, and the effective strength be taken at one-third of that amount, or 2 tons a square inch, in order to allow for the joints, the result obtained is that the greatest possible strain to which it could be exposed, namely, in the case of the vessel being supported at the ends only, is 2⅛ tons a square inch, or 6 per cent. in excess of the tensile strength of the material; while in the other case of the vessel being supported only at the centre, the strain of 1⅞ ton a square inch is 6 per cent. less than the strength of the material. In the iron ship, if the tensile strength of the material be taken at 20 tons a square inch, and the effective strength at three-fourths of that amount, or 15 tons a square inch, the greatest strain to which it can be exposed, namely, 17 tons a square inch in the case of the vessel being supported at the ends, exceeds the strength of the material by 13 per cent.; and in the opposite case of the vessel supported at the centre, the strain of 13 tons a square inch is 13 per cent. less than the strength of the material.

The general result therefore as regards the comparative strength of the iron and wood ships appears to be that in the position causing the greatest possible strain in each case, namely, when the ship is supported at the ends only, the strength of the material is deficient for resisting the strain by about one-eighth in the iron ship and one-sixteenth in the wood ship; and in the other position of strain, namely, when the ship is supported in the middle, there is an excess of strength in the material of about one-eighth in the iron ship and one-sixteenth in the wood ship.

The iron used in the framework of iron vessels is applied in various forms of section of single or compound structure. Those which are frequently employed are shown in the sections, Figs. 4529 to 4550.

For keels, the section shown, Fig. 4529, is in common use, as seen at L, Fig. 4525. It consists of a plain parallel bar about 8½ in. deep by 3 in. thick for a 1200-ton ship. This is forged in lengths of about 20 ft., and then pieced up by welds into two or three lengths for the entire ship, having scarfed joints of a length of eight times the thickness of the keel, which gives room for as many rivets as are required to correspond with the section of the keel. Fig. 4530 is a deep keel of plate-iron, made by putting two or more plates side by side, breaking joints in every way. The plates are 1 to 1¼ in. thick and from 3 to 4 ft. deep; they are adopted when a forging of the required size would be too large and heavy, say for vessels of 2000 tons and upwards; and where the scarfing would also be comparatively imperfect. This arrangement is specially adopted in order to be made to serve as a keelson as well. The floor angle-irons T T have to be turned up at the foot so as to be riveted through and through the keel-plates; and the floor-plates U U are thus made in two pieces, one on each side of the keel. The keelson angle-irons V V are put on the top of the floor-plates and riveted through and through the top edge of the keel-plates. Fig. 4531 is the dished keel, specially suited to flat-bottomed vessels, in which it forms an excellent trough for drawing off the last drop of bilge water. It is made of plates about 1 in. thick, bent or rolled to the required section. The trough is made of a shape to suit the circumstances, from 6 to 8 in. wide and 2 to 4 in. deep. Fig. 4532 shows an arrangement with a flat plate as a substitute for a keel for flat-bottomed vessels, where the draught is limited to the smallest possible amount; and a water-course is obtained by an opening W in the bottom edge of the floor-plate U and by cranking up the angle-iron to correspond.

4529.



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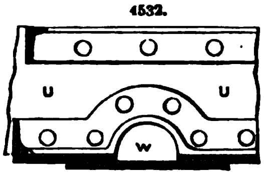

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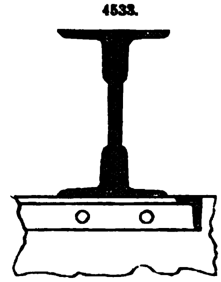

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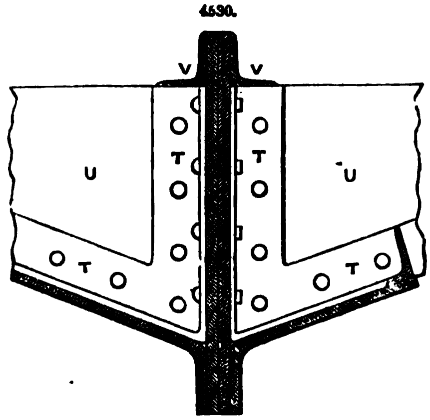

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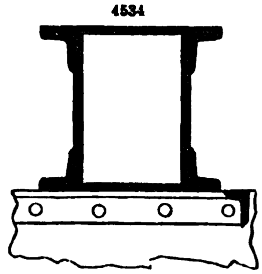

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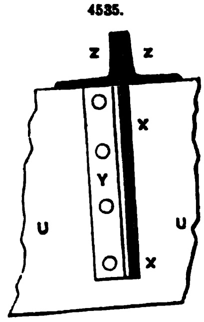
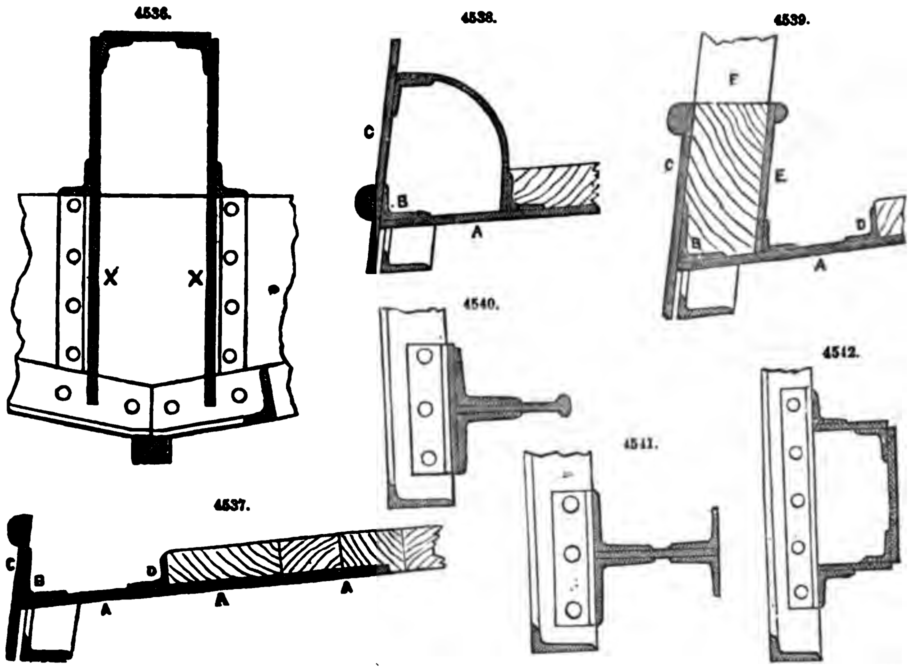


4531.

For keelsons, the section, Fig. 4533, is that required by Lloyd's rules, and is two-thirds the depth of the floor-plates. Fig. 4534 shows the box keelson, seen at G, Fig. 4525, which is recommended as superior to the preceding, its advantages being the larger section of the top member and the lateral stiffness obtained by the box form. Fig. 4535 is what is called the *intercostal* keelson, seen at H H in Fig. 4525, which is of great value in keeping the floor-plates in a vertical position, so as to retain their best strength. It consists of short pieces of plate X, introduced between the floor-plates U, and riveted with angle-irons Y to each of them; thus forming a continuous line fore and aft, with double angle-irons Z back to back, riveted through the top edge of all the intercostal plates. Fig. 4536 shows a box keelson which is also intercostal; this is made either with double intercostal lines of plates X X, as shown in the section, or with a single line, by one side only of the keelson being let down between the floor-plates, instead of both sides.

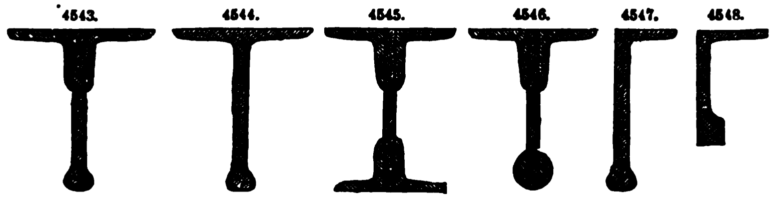
Figs. 4537 to 4542 show sections of different forms of stringers. Fig. 4537 is a gunwale stringer, such as is usually adopted, as seen at A in Fig. 4525. The word gunwale is employed to designate the group of iron used along the edge of the main deck at the sheerstrake C; and the horizontal flat plate A, Figs. 4537 to 4539, is called the gunwale stringer, and the angle-iron B

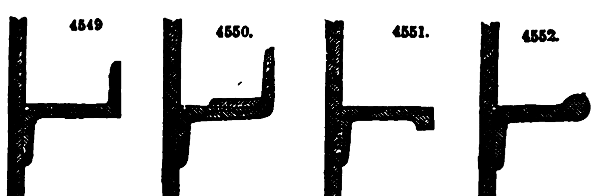


the gunwale angle-iron. The size of the gunwale stringer A is 36 in. wide by $\frac{1}{2}$ in. thick in the midships for a vessel of 1200 tons. The inner angle-iron D is specially valuable as forming an abutment for the edges of the deck-planks. Fig. 4538 is a box form of gunwale, which has special stiffness and solidity. Fig. 4539 shows a form of gunwale with a vertical stringer E, consisting of an inner plate set up on edge; the groove between this stringer and the sheerstrake C is made to receive the wood stanchions F for the bulwarks, and between the stanchions the groove is filled up solid with wood. Figs. 4540, 4541, are two forms of stringer specially suited for lower hold stringers, or for any position where they cannot have the advantage of being connected to the end of deck-beams; Fig. 4541 is seen in position at K K in Fig. 4525. Fig. 4542 is a box form of lower hold stringer, suited for similar positions to Figs. 4540, 4541, but capable of being made of much greater strength and stiffness.

Figs. 4543 to 4548 are sections of different forms of deck-beams; amongst which may be specially noticed Fig. 4544, because with this section the largest amount of strength is obtained

4543. 4544. 4545. 4546. 4547. 4548.





with the least weight of material, since the iron is in the form best suited for bearing a superincumbent weight, and there is no loss of material by laps of riveted joints.

Figs. 4549 to 4552 are sections of different forms of frame iron. Of these, Fig. 4550 is commonly

6 U

used; and it possesses the advantage of the reversed angle-iron, being curved off at the bilges across the bottom of the vessel, to form the top of the floor-plates. The three other sections, Figs. 4549, 4551, 4552, are decidedly better, so far as the side frames are concerned, but are not so well adapted to combine in the formation of the top of the floorings.

The use of iron in the construction of vessels affords great facility for obtaining the necessary strength in keels, stem and stern posts, screw port frames, and other parts, by the introduction of large forgings. An illustration of this is afforded by the stern-post and screw port frame of the 'Great Britain,' shown in Figs. 4553 to 4555.

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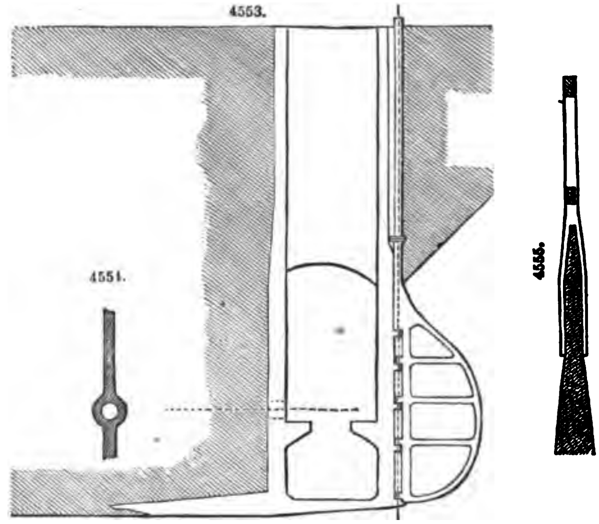

4554. 4555.

The application of iron for building vessels is peculiarly advantageous in the special class of screw colliers with hollow bottoms for carrying water ballast. The traffic in which these vessels are engaged does not usually provide any return freight, and a great commercial advantage is obtained by this method of water ballasting for the return voyage, which is accomplished without any delay and with but little cost. Figs. 4556, 4557, show transverse and longitudinal sections of

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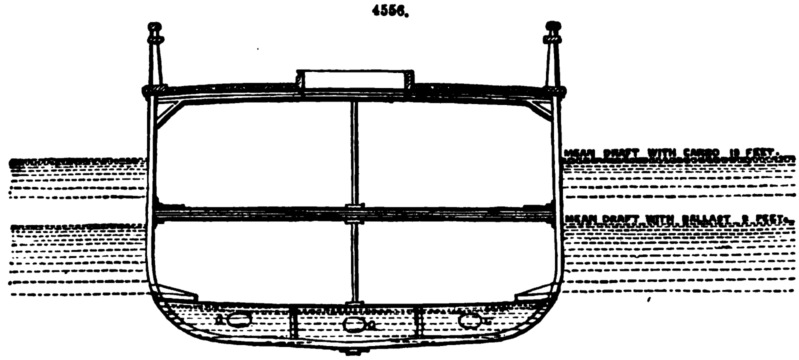

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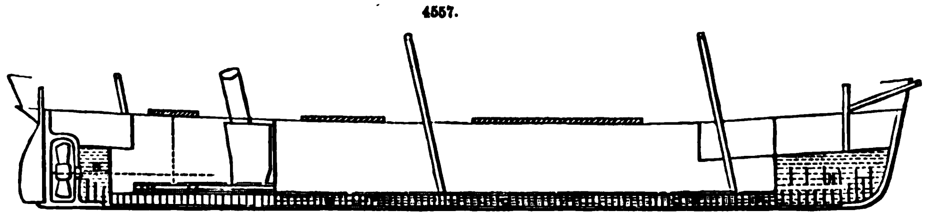

an iron screw collier with water ballast, in which it will be seen that a water-chamber is formed by the hollow space of the double bottom G G, and a chamber is also obtained in each of the extreme fore and aft compartments H and K, Fig. 4557. When the vessel is required to be ballasted, the large sea-cocks are opened and water is admitted into the hollow bottom G and the aft compartment K, so as to fill these two portions; and then the water is also admitted into the fore compartment H, to such an extent as may be found necessary for adjusting the draught of water and the due immersion of the screw. When the vessel has arrived in port, the steam-pumps are set in action for pumping out the ballast water; or in a dry harbour at low water the large sea-cocks are opened, and then the water is easily and quickly got rid of within the short time of the cargo being taken on board; and the vessel is thus got ready for sea again without having experienced any delay on account of discharging ballast. Figs. 4556, 4557, represent the iron screw steamer 'Annie Vernon,' which is of 518 tons gross register, and 70 horse-power. The weight of water ballast contained in the hollow bottom chamber G is 120 tons, in the aft compartment K 20 tons, and in the fore compartment H 30 tons, making a total of 170 tons of water ballast; and the

cargo of coal or iron ore which the vessel carries is about 700 tons. The mean draught when in ballast is 8 ft., and when fully loaded with cargo 13 ft., as shown in the transverse section, Fig. 4556.

There is perhaps no branch of iron shipbuilding in which more special advantages are obtained from the use of iron than in the construction of flat-bottomed boats for river navigation. The extremely small draught of water thereby obtained is a matter of great difficulty except by the use of iron as the material of construction. A specimen of vessels of this class is shown in Figs. 4558 to 4560, which represent an iron paddle steamer, 226 ft. long, 30 ft. beam, and 7 ft. depth of hold,

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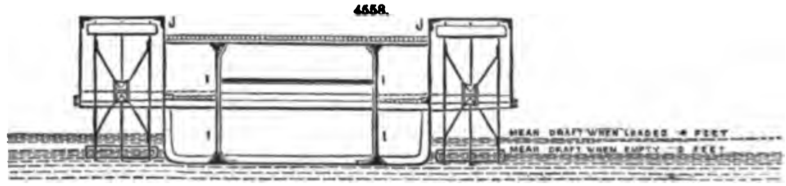

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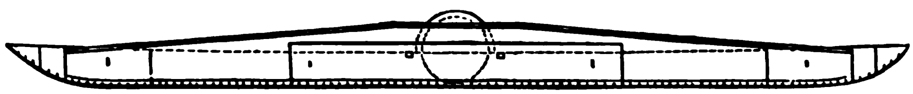

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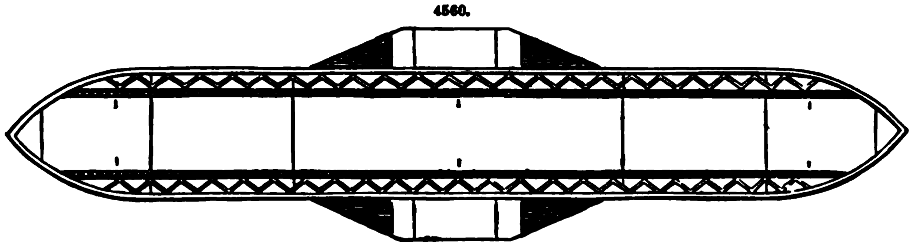


fitted with engines of 170 horse-power. This steamer draws only about 2 ft. of water when light, and can be loaded with coal and cargo to a depth of 4 ft.; it maintains a speed of 14 statute miles an hour when steaming alone, and 11 miles an hour with one barge in tow, 200 ft. long and 30 ft. wide, with 370 tons of cargo on board, having a draught of 4 ft. In this construction of vessel two longitudinal iron girders I I are introduced, rising considerably above the level of the deck, in addition to the sides of the vessel being raised as girders to the height of the paddle-boxes, as at J J, Fig. 4558. The girders I I are required in order to obtain the necessary longitudinal strength as a girder for carrying the weight of the engines and coal, the hull of the vessel being totally insufficient for this on account of its necessary shallowness and lightness. This vessel is made without a keel, Fig. 4558, and with a spoon bow, Fig. 4559, which is found to be a very advantageous form for facilitating getting the vessel off the sandbanks that are so frequently met with in such rivers as the Ganges and Indus where these vessels are worked, in which it is found impossible to avoid at times going aground on the sandbanks.

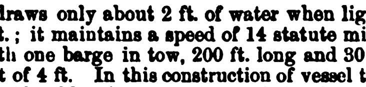
The mode of riveting adopted in large first-class vessels is principally what is termed chain-riveting, both in the longitudinal and vertical joints; but in addition the principal stringer-plates in the upper part of the vessel, and the sheerstrakes in the midships, have further rows of rivets with increased lap of the joint-plates, making the joints in these cases treble or quadruple riveted.

The joints for the plating have now become more perfect than formerly, by the use of the planing machine. The edges of the plates for the butt-joints are planed perfectly straight and smooth, and they are thus brought into accurate contact with each other, so as to form a true and close joint, which could not previously be attained by shearing and the too common practice of hammering up the edges of the plates. All necessity for undue calking and the use of lining strips is thus avoided, and the best strength of the material is imparted to the ship. The quality of iron employed for shipbuilding should in all cases be equal to a tensile strength of at least 20 tons the square inch, and a direct and habitual system of testing should be constantly carried out.

We are indebted to Thomas Smith, M.I.N.A., of Dublin, for the following practical instructions in iron shipbuilding:—

Keels.—In boring keel-bars, be particular to have the top row of rivet-holes marked no lower down than is necessary to make a good and close fit of the garboard strake at the top row of holes, and on no account weaken the keel-bar by having the lower row of holes bored too low down; at the same time care must be taken to have a distance equal to the diameter of rivets between the lower edge of upper row and upper edge of bottom row; a distance of two diameters between the centre lines of the top and bottom rows, Fig. 4561. In marking off the holes, attention should be paid to having them properly divided; that is to say, having the upper rivet exactly between the two lower rivets. Make the length of scarfs of keel-bars at least ten times the thickness of keel-bar. Lloyd's Rules give only eight times, but this is too little to make a substantial connection.

4561.



Before commencing to drill the scarfs, have them drawn perfectly close, and see that the ends are brought together, and are a good fit.

It is not necessary to drill more than three holes in scarfs for stitching, and these should be on top part, so as not to weaken the keel-bar more than necessary.

The upper side of scarf should be calked before the frames are laid across keel, and the under side after the keel-plates are riveted.

The butts of the garboard strake must be spaced so as to be well clear of the butts of keel-bar; say at least 30 in. when practicable, and with care this distance can generally be given.

Have the position of all frames marked on the keel with a centre punch before any of the frames are laid across; this will save a deal of unnecessary trouble.

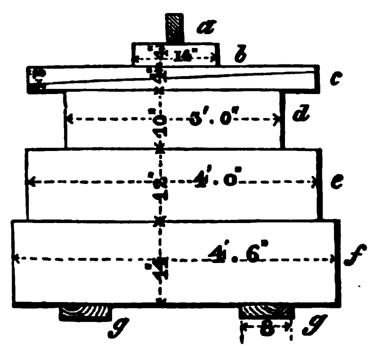
See that the keel-bars are properly shored, straightened on top edge, and got quite fair previous to laying any frames over them. Attention must also be paid to fairing the keel fore and aft by a line, after the frames are up in place, before commencing to fit any of the garboard strake on. In Fig. 4562, *a* is the keel; *b*, cap-piece of oak; *c*, gluts or wedges; *d*, redpine; *e*, redpine; *f*, redpine; *g*, slabs.

It is important to keep the keel a reasonable height from the ground, so as to allow room for the workmen to get under the vessel's bottom without being too much confined; otherwise they cannot make good work of the riveting and calking. In settling this point, bear in mind that if the vessel has a flat floor the blocks must be laid higher.

Let the keel-blocks be spaced about 7 ft. 6 in. apart, and have a double block between, say every second and third block alternately. This will allow for shifting any blocks that may be necessary to get at the work without fear of the vessel settling down. Have the three or four last blocks laid on fore and aft logs, as the vessel will be certain to sink at after end, if anywhere.

Fig. 4562 shows height and dimension for keel-blocks, suitable for vessels of the usual run.

4562.



It is well to have the keel riveted as soon as possible, to prevent dirt or any rubbish getting down between the keel and garboard strake.

Flat-plate Keels.—If for a vessel building to class at Lloyd's, the breadth and thickness must be as follows;—In vessels of 500 tons and under, 2 ft. wide; from 500 to 1000 tons, 2 ft. 6 in. wide; 1000 tons and upwards, 3 ft. wide. The thickness of plates in all cases to be not less than one and a half times the thickness of the garboard strake.

It is desirable in flat-plate keels that the butts of the garboard strake should be clear of the butts of keel-plates at least two spaces of frames on both the port and starboard sides; and for this reason the keel-plates should be made in such lengths as will suit this; also see that the butts of the keel-plates are fair between two frames, as this is necessary to facilitate the putting on of the butt-straps.

In all cases it is recommended to treble-rivet the butts of keel-plate, making the butt-straps as wide as can be got in between the flange of the frame angle-irons and heel-pieces on next frame.

Stern-posts and Stern-frames.—In a screw steamer, care must be taken in boring any holes about the boss that may be required, and this should be done previous to putting the frame up in place. Mark off the lead of these holes so that they may be bored in the proper direction, and thereby have a proper divide on the inside of the boss.

Particular attention should be paid to taking out any twist that may be in the stern-frame when it comes from the forge, and be careful to see that the bosses on both outer and inner post lead fair fore and aft.

In the upper portion of stern-posts it is only necessary to have one row of rivets for the rudder-trunk. Some builders and inspectors prefer to put two rows, but it is only waste of time doing so.

In the riveting of bosses, it is absolutely necessary to have the countersink bored out a sufficient depth, so that when the engineers have done boring and fitting in the stern-tube, there will be plenty of countersink left to hold the rivets secure.

In putting in the boss-rivets it is a good plan to cool them at the points, so that the heads may thereby be well tightened up.

Bear in mind that it will save trouble, and make better workmanship, if you arrange the plating so that a strake will cover the boss.

Make the scarf of your stern-post always on the port side, and do not have the length of the knee or keel portion to exceed 10 ft. 6 in., as that length is about as great as can be conveniently taken on ordinary trucks, if the post has to come by railway from the forge.

Stems.—The mould for bending the stem too should be made off the inside line of stem, and if it is not turned before the scarfs of keel-bars are cut and finished, it is well to measure the total length of the keel on the blocks, and contract or increase the length of the stem-bar, as the case may require, to make up the exact length. Do not drill any holes in stem until it is turned to shape, and be careful to have the scarf on the right side to agree with forward length of keel-bar.

In forging stem-bars, have the fore side shaped to a flat half-round, and see that there is no twist in the bar.

Rudder-frames.—Should you make the rudder forging in scantling, according to Lloyd's, bear in mind that if for a spar-deck ship, or vessel with full poop and forecastle, the diameter of the rudder-head must be in accordance with the dimension given for the gross tonnage, and not the tonnage under main deck.

Attention should be paid to having the rudder-pintles all in a fair line. Have a steel washer for the pintle at heel of rudder to work on. It is always the best plan to make the rudder to unship, and the space for unshipping at each pintle should be about 1 in. deeper than the length of the pintle.

In a screw vessel attention should be paid to keeping the pintles clear of the bracket on the after-post for outside shaft bearing.

In rudder forging for vessels of from 200 to 500 tons, have a stay across centre of rudder from rudder-post to bow; and in vessels over that tonnage, two stays; width of stays about 3½ in. The stays may either be made with the forging or of cast iron fitted in. The space between the plates of rudder should be filled in with either wood or Portland cement. Thickness of rudder-plates need in no case exceed ½ in.; and it makes the most substantial work to have the rudder-plates snap-riveted.

Rudder-bands.—Pay particular attention to see that the centre of pintles are correctly set off before boring same, by striking a line up centres, to see if these are in a line, and that the back is straight and fair; this applies also to the stern-post. See that the rudder-trunk is made of sufficient size to allow the rudder-stock to be got up easily, say from 8 to 9 in. internal diameter for a 4 to 5 in. rudder-post; other diameters to be in like proportion. Attention should be paid to having the rudder-trunk and angle-iron binding the foot of trunk to outside plating a good fit, and the bottom carefully calked.

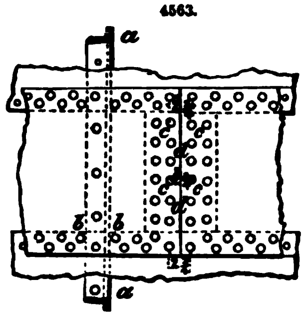
Rudder-stops.—The proper angle for a rudder to travel is 42 degrees on each side of centre line of ship, and the stoppers should be made to suit this. Be particular to have the stops made strong enough and well secured to stern-post. The rudder working easily is a matter of great importance, and requires particular attention in the lining-off and putting in place.

Angle-iron Frames.—Previous to putting any work on the bars, have them examined to see that there are no cracks or blemishes, as angle-bars are constantly sent from the iron-works without care being taken to see if they are sound.

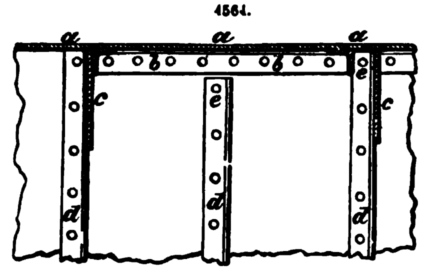
In punching the frames, see that the holes are properly divided; and as an example, for double-riveted laps with ¾-in rivets, have the top hole 4¼ in. from upper edge of lap, or 6½ in. from centre of lap, and the lower hole 3¾ in. from lower edge of lap, or 6 in from centre of lap, on plate mark on the mould on board. Fig. 4563 shows the proper spacing of rivets for double-riveted laps with ¾-in. rivets. *a*, is the frame; *b*, rivets to be as close to frame as head of rivet will permit; *c c c*, chain-riveting at butts to have the holes punched opposite each other; *d d*, butt-straps to be fitted as close as possible between laps of outside strakes.

In single laps have a hole punched 5¼ in. each side of centre of lap, the lap being 2⅝ in. Divide the spacing of holes for rivets between one lap of plates and the next, as near to eight times the diameter of the rivet as you possibly can arrange.

4563.



4564.



In frames that run up to form sides of poop, forecastle, or bridge, have those with no beam on, cut off low enough to allow the lug-pieces for securing stringer-plate to shell to run from beam to beam, as Fig. 4564, where *a a a* is the poop-deck stringer-plate; *b b*, lug; *c c*, beam-knees; *d d d*, frames; *e e*, this hole to be made after the plating is on. A hole should be punched in head of the frames that are cut short for lug-pieces passing, about 3 in. down; but it is best not to put this in until the vessel is framed and faired.

In frames that step on the knee of stern-post or stem, do not neglect to have them cut to the proper thickness to allow the plating to come on.

The heel of frames bearing on keel should be carefully cut and finished, so as to butt close together, and the bearance not to be greater in width than the thickness of keel, otherwise a proper job will not be made of the garboard strake.

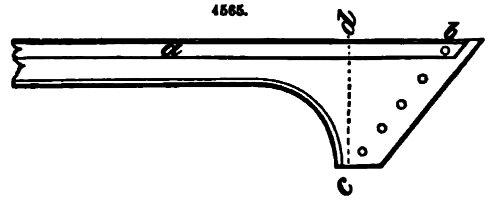
The inside flange of angle-iron frame should be punched so as to suit size of the reverse frame, and care should be taken to see that the holes are so punched as to take the centre of flange of reverse frame.

It is necessary to see that the heel-pieces are quite fair with under side of frames, and that they bear true on the keel. One or two holes only should be punched in the frames, for the beam-knee, prior to putting up the frames.

Length of beam-knee is measured square off, and the holes should be divided round the sweep, the centre of lower hole placed about 2 in. from lower edge of knee, Fig. 4565, in which *a* is the reverse iron; *b*, hole punched to take reverse bar on beam; *c d*, measurement at right angles to top of beam—not obliquely. Do not have the upper hole in head of frame for upper

rivet in beam-knee punched until the frames of vessels are all faired and sheered, as in case the beam requires to be lifted or lowered, it spoils the hole, and as this rivet passes through the angle-iron on beam it is necessary the hole should be true to make good work. The same rule applies to the bottom hole in beam-knee, as it looks very unworkmanlike to see a blind hole there.

4565.



The double frames at the bulkheads should be punched for rivets 4 in. centre to centre, and should be chipped at both edges previous to hoisting up in place, otherwise difficulty will be found in making a tight job of the calking.

If the vessel has a sheerstrake with jump joints, see that the holes punched in frames are clear of the lap of both the inside and outside sheerstrake.

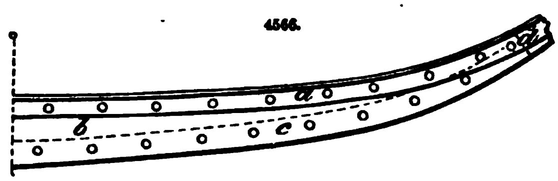
Reverse Frames.—The frames with no beams on to have the reverse bars running up to main-deck height, and these to butt in centre of floor, having heel-pieces of angle-iron on opposite side of floor-top, of sufficient size to form top flange for keelson fastenings.

Short reverse frames to run up to upper turn of bilge; but if there is a spirketting plate on 'tween-deck stringer, then the short reverse frames should run up to top of said plate.

Butts of the short reverse frames should be about 4 ft. each side of centre-line, alternately on the starboard and port side; but should these butts come in the way of boiler or other keelsons, the distance must be altered to suit.

Holes should not be punched in reverse frames in way of floor-ends, unless there is a clear space of ¾ of an inch from outside of rivet-hole to lower edge of reverse frame, as in Fig. 4566, where *a* is the reverse bar; *b*, floor; *c*, frame; at *d* rivet this flush, and let reverse bar lie over it.

4566.



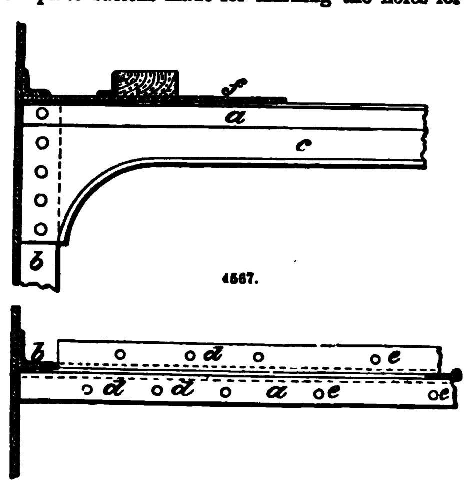
The reverse frames across the floor-tops at ends of vessel will require to be bevelled to suit the rise of floors and make a fair seat for the centre keelson. These bevels can best be taken when the vessel is ribanded and shored up.

See that the butts of the reverse frames are quite close and fair to each other. Accuracy of the workmanship adds greatly to the strength in all parts of an iron vessel.

The reverse frames must fit well over the floor-ends, and see that the floor-ends are thinned down to suit this.

The double reverse frame on floor-top should be neatly fitted on. Get a straight-edge, to see that it is fair, and attend to having all the scarfing or lug-pieces rivted close to floor-plates.

Angle-irons on Beams.—The holes must be punched to suit width of deck-planks; the centre should be marked on the beam, and have two template battens made for marking the holes for punching in the angle-irons, so that they are equally spaced and divided. The holes for the fore-and-aft tie-plates and stringer-plates should also be set off on these battens and the holes marked and punched accordingly. Holes for tie-plates and stringer must be punched to suit the diameter of rivets intended to be used, and those for the deck-plank to suit size of deck screws or bolts.



4567.

Holes should not be punched nearer to beam-ends on top flange of angle-iron on beam than about 6 or 7 in., in case they should not come fair with the stringer angle-iron holes. These holes are best drilled through top flange of beam angle-iron, after the stringer is put on, the holes being previously punched in the stringer-plate.

One angle-iron only on beam to run out to beam-end, and to take a rivet through angle-iron on beam-knee and frame, Fig. 4567. *a* is the reverse bar on beam; *b b*, frame; *c*, beam; *d d d*, rivets for stringer-plate, 6 in. or 7 in. apart; *e e e*, ditto for deck-plank twice the width of plank; *f*, stringer-plate.

The holes for riveting stringer-plate to angle-iron on beams should be about eight times the diameter of the rivets apart

See that the angle-irons on beams are properly levelled at each end, so as to give a true seat on which to rivet the stringer-plates.

Floor-plates.—Floors should be twice the height above keel at floor-ends that they are at centre-line, and should be parallel to base-line athwartships, as far as practicable. Floor-plates at ends to be the width of inside flange of angle-iron frames.

See that the floor-ends are neatly thinned down, so that the reverse frames fit over fair and close.

Floor-plates should be sheered ½ in. less than the shape of frames.

The floor-ends where they have been thinned down for reverse frames should be chipped flush with the frame, both inside and out, previous to keelson or shell plating going on.

Limber-holes should be cut so as to clear frames, heel-pieces, lug-pieces for keelsons, intercostals, and so on.

At the extreme ends of vessel, the floor-plates should be increased in depth to say twice the depth of floors amidships, or until they measure say 2 ft. across the top, from outside to outside of frame.

Floor-plate for the transom-frame should be put on the depth of the knuckle, so that the stern timbers are sufficiently secured.

Main-deck Stringer.—In the case of an inside sheerstrake going up only to under side of main-deck stringer-plate, the holes in said stringer for the angle-iron bar will require punching the thickness of the inside sheerstrake nearer the outer edge of stringer-plate, so as to catch the centre of the bar, Fig. 4568. *a*, reverse bar; *b*, beam; *c*, inside sheerstrake; *d*, outside sheerstrake.

Should the inside sheerstrake not run up above the main-deck stringer-plate, see that the stringer projects over the frames the full thickness of the inside sheerstrake.

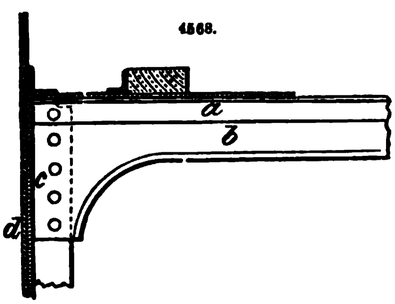
Attention should be paid to punching the holes in stringer-plate for the angle-iron bar, to see that they are not punched with the same die as is used for the outside plating, no more countersink being required than is sufficient to keep the punch from choking, and the stringer-plates should be well sheered to form of side of vessel, or a bad bearing will be left for the gunwale angle-iron bars.

It is advisable to have the stringer-plates riveted to the beams, also the butt-straps riveted as soon as possible, and see that the butts come well clear of butts of sheerstrake.

Previous to commencing with main-deck stringer, see that the heads of frames and reverse frames are not higher than the beams.

Have all holes for the diagonal tie-plates in main-deck stringer-plates punched before putting in place. It is well in all cases to have the butts of main-deck stringers treble-chain riveted.

4568.



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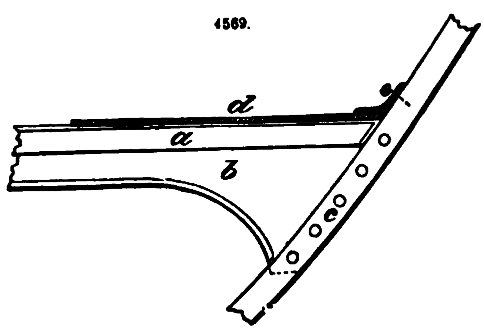


'Tween-deck Stringer.—Have all beams in and riveted before commencing to put in 'tween-deck stringers.

In vessels where the alternate reverse frames do not run up to height of hold-beams, see that holes are not punched in the vertical flange of stringer angle-iron, unless it is intended to rivet a lug-piece on the frame, for fastening the stringer angle-iron to the frames with no reverse bar running to that height.

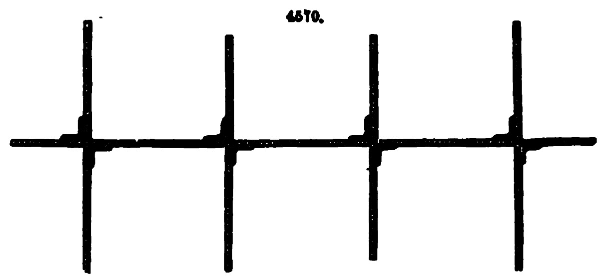
In the after-peake, where there is a considerable flare in the sides of vessel, it is advisable to use a bar of larger dimensions for the stringer angle-iron, so as to get a good hole in the bar, not too near the edge, and thereby weaken it considerably. In Fig. 4569, *a* is reverse bar; *b*, beam; *c*, frame; *d*, stringer-plate; *e*, rivet must not be too near edge of angle-iron, nor too far down in its bosom.

Poop-deck Stringer.—In putting on poop and forecastle deck stringers, have the stringer-plate sheered to come out to the outside edge of frames; so that when the forecastle or poop plating goes on it will butt up against it.

Holes should be punched in edge of centre stringer-plate aft for fastening plate, for taking rudder-trunk, and fixing stuffing box round rudder-head to.

Wash-plates. — Do not put wash-plates between bulkheads and floor-plate on adjoining frames, so as to allow the water to get freely to the pumps.

4570.



Fitting-in wash-plates between floors may be done as shown in Fig. 4570; but if they are required to serve as intercostal keelsons, four angle-irons at each floor will be necessary, and they must be made to fit close on.

Bilge-keelsons, &c.—In putting on the lug-pieces for keelsons, see that they are quite fair with the edge of inside flange of angle-iron frame, and the fore-and-aft flange of reverse frame.

The lug-pieces should fit close against the frame angle-iron, and be well riveted thereto.

In keelsons formed of two angle-irons with a bulb-iron between, allow between the angle-irons a $\frac{1}{8}$ in. extra, beyond the thickness of the bulb-iron, in marking off the holes for rivets in reverse frames and lug-pieces so far as the bulb-iron extends.

The lug-pieces for three frames forward and aft of the finish of bulb-iron between angles should not be punched, but drilled to suit a tapered slip neatly fitted between the two keelson angle-bars.

The butts of angle-iron bars of keelsons should be so shifted as to be at least two spaces of frames clear of butts of other keelsons, and as far as practicable clear of butts of outside plating.

If the angle-irons for keelsons are 4 in. or more, the holes for rivets should be punched each side of the centre-line, Fig 4571. *a*, in some cases, 5".

Athwartship flanges of bilge-keelson angle-irons in way of breasthooks should not be riveted till the breasthook-plate is in.

See that the breasthooks are got in as soon as possible, and that they are well fitted and securely riveted in place. A man-hole should be cut in breasthooks where necessary.

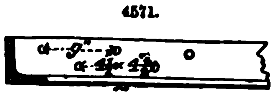
Should the breasthooks or pointers aft in a screw vessel not be high enough above the stern-tube, they should not be riveted until the boss for shaft is bored and finished, on account of leaving room for men fastening bolts, and so on.

Have the position of bilge-keelsons carefully marked off on frames, and see that they are sheered fair.

It is advisable to keep the bilge-keelsons clear of ribbons as far as possible, in case the lug-pieces or reverse frames want any setting up.

When practicable, have the height of lower bilge-keelsons at aft-peake bulkhead made to correspond with the height of top plate of centre keelson, so as to get a breasthook-plate riveted between the bilge-keelson angle-irons and top of centre keelson, Fig. 4572, where *a a* show bilge-keelsons; *b*, breasthook; *c*, centre keelson; *d*, frame; *e*, floor; *f*, garboard strake; *g*, keel. This makes a good finish and a very secure fastening.

4571.



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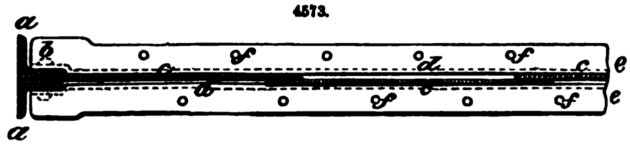

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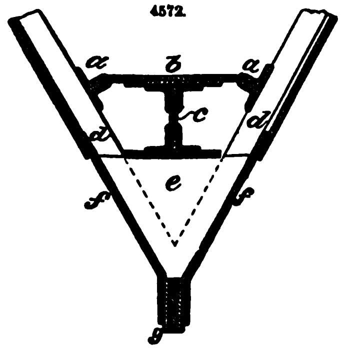

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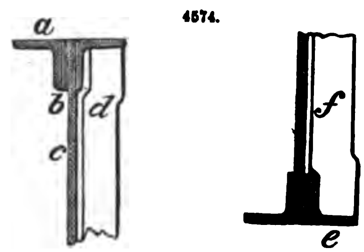


Bulkheads.—See that the bulkhead-frames are all chipped fair on edges, prior to putting up in place, so that the bulkhead plates can be properly calked under the shelf-plates, stringers, and so on.

The bulkhead-plates should be calked outside between the frames, as well as both sides inside, and round the edges of the gravit-plates, for keelsons passing through, see that the gravit-plates are a good fit and neatly put on. The plates for gravits should be $\frac{1}{8}$ in. thicker than the bulkhead-plates.

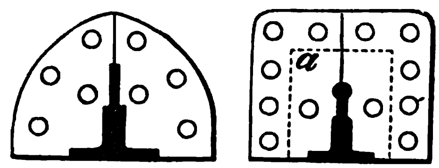
The beam angle-bars should be cut short on bulkheads, so that they lie in the bosom of the bar, Fig. 4573, and the angle-irons forming the beam on bulkhead should be not less than 3 in. deep, so that a good rivet may be got in through the head of the vertical angle-iron bar. *a*, Fig. 4573, is the side frame; *b*, holes to be left blind, and riveted after the rest of bulkhead; *c c*, bulkhead-plates; *d d*, slip to be set to curve of beam, and to equal angle-iron in depth; *e e*, the vertical flanges of these bars not to be less than 3 ft. to get a good rivet in head of vertical bar; *f f f*, holes to suit deck-planks. The vertical bars should have a hole for a rivet punched through both side frames and should be neatly joggled for it at foot. The same applies to both the reverse angle-irons on the top edge, Fig. 4574. *a*, beam's reverse bar; *b*, slip; *c*, bulkhead-plate; *d*, vertical bar, to be properly joggled over; *e*, side frames; *f*, vertical bar.

In plating bulkheads, attention should be paid to see that the first plate is at right angles with the keel; also see that the reverse angles forming the beam are not sagged down in centre or standing too high at centre or ends.

The fore and after peake bulkheads should be plated in the vessel, after the frames are faired, not from the mould, or board, in case the frames may not be the proper fit at the bottom. This applies more especially to vessels with flat-plate keels.

Attention should be paid to the fitting and punching of the gravit-plates, to see that the holes are sufficiently close and regular, and that the plates are not made larger than necessary; as, if so, they cannot be calked tight. It is also advisable to have a rivet as close as practicable to the hole for keelson-bars passing through the bulkhead, Fig. 4575. *a* in this figure indicates the position of boiler-keelsons in engine-room.

4575.



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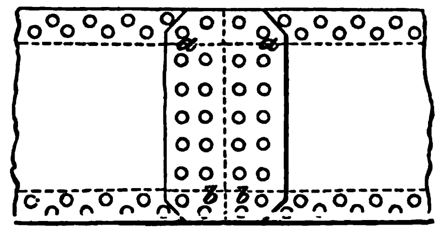


Inside Sheerstrakes.—The butts of inside sheerstrake should be double-riveted through inside sheerstrake and butt-strap; the row of rivets next butt of plate to be riveted flush before the outside sheerstrake is put on, Fig. 4576. *a a*, these two rows, through inside and outside sheerstrakes and butt-strap, and so on; *b b*, these two rows through inside sheerstrake, and butt-straps, and riveted flush, before outside plate is put on.

If there is only one frame between the butts of outside and inside sheerstrake, see that the plates are butted fair in the centre, between frames. Same rule applies to the outside sheerstrake, so that there is a full frame space of shift between the butts of outside and inside sheerstrakes.

The holes for rivets in the gunwale angle-iron bars should not be punched with the same die as used for outside plating, on account of giving too much countersink.

In inside or ordinary sheerstrakes attention should be paid to seeing that the holes for the vertical flange of gunwale angle-irons are punched the proper height, so that the holes may be fair in the centre of bar.

Outside Sheerstrakes.—In outside sheerstrakes, make sure that the gunwale angle-iron bars on the top edge of sheerstrake are properly faired all fore and aft, as also the top edge of the sheerstrake itself. If possible, it is well that the gunwale angle-bar should be not less than 4 in. by 4 in., as this width will give a better chance of making all fair holes.

Beams.—The beam-mould should be made the full breadth of the vessel, so that the total length of beam can be taken off and the correct bevel taken at both sides. The mould should be made the full depth of the beam-knees.

Have the bottom hole for rivet in the beam-knee punched, so as to allow 1¼ in. of iron from the under side of rivet to bottom of knee.

Poop-beams.—Have the poop-beams put up and bolted to the frames, but do not have them riveted until after the stringer-plates and tie-plates are all faired and riveted. This should be specially attended to, as it frequently occurs that if the beams are riveted first the knees get twisted, and set the beams up or down, as the case may be, making bad and unfair work of the stringer and tie plates.

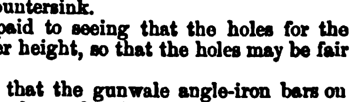
To keep the poop-beams the proper spacing, it is a good plan to have a long plank, say in scantling, about 8 in. by 3 in. or 2½ in., and have marked off on this plank the spacing of the beams, cutting out a notch for each beam; and when the beams are put up, let them go into the notches, and have the plank shored up from main deck. By attending to this, you will have all your beams equal distant and to one curve, which will add considerably to the appearance of the cabin ceiling, and so on.

Framing of Hatches, &c.—In making hatches, put in the fore and aft angle-iron bars first; have them made a good and neat fit; see that they are straight fore and aft, and then put in the bulb-iron or plate for fore-and-aft carlings; seeing this is also a good fit.

An angle-iron bar, about 5 in. by 5 in. by ½ in., cut in lengths to suit, and fitted in the corners of the hatches, makes a much better finish than to knee the bulb-iron or bend the plate-knee.

The beams that form the fore-and-aft ends of hatchways should have reverse angle-irons, not less than 3 in. deep, so that the holes in plate-knees may be punched to allow ⅝ of an inch of iron from top of rivet-hole to top of knee-plate, Fig. 4577. In the figure, *a* is the beam; *b*, reverse bar on beam; *c*, fore and after; *d*, plate-knee, in corner of hatch, inside; *e*, this rivet to be not less than ⅝ from edge.

4577.



Outside Plating.—Attention should be paid to having the butts of the garboard strake clear of the scarfs in keel, and that the butts of the garboard plates should have three frames between them from the starboard to the port side throughout, Fig. 4578. *a a*, the butts of these go a frame farther forward on starboard side (see *f f*); *b b*, the butts of these do the same (see *e e e*); *c c*, butts (see *f f*); *d d*, garboard-strake butts (see *e e e*).

In order to have the butts of the outside plating a clear two spaces from the bulkheads, have the plates that come in wake of bulkheads a space of frames more in length than the average length of plating.

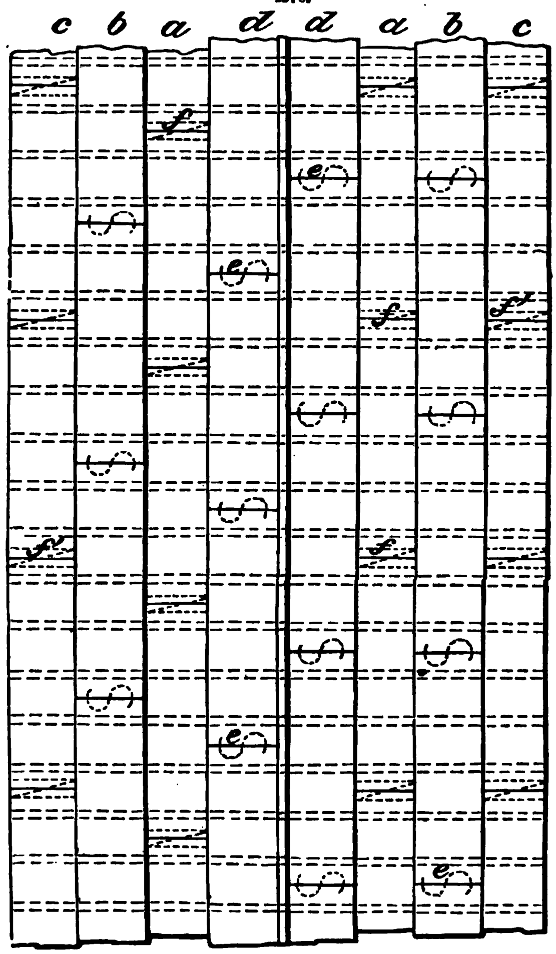
Have the sides of plates, with the maker's stamp on, put to the outside of ship, so that the surveyor may see it, on account of the classification.

In the butts of bilge strakes, if the bilge is at all quick, the edges of the plates should be sheered with a slight curve.

In plating vessels, attention should be paid not to put too much weight of plating on the top sides until the garboard bilge and bottom is all plated and riveted.

The holes for rivets in the lower edge of double riveting should be punched as near as possible to the edge of frame, Fig. 4579, and spaced, say, for a 3-in. flange and ¾-in. rivets, not more than 8 in. pitch. *a a* are the frames; *b b*, rivets next frames to be as shown.

4578.



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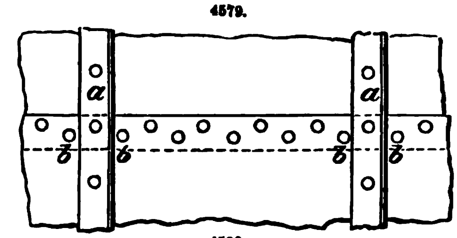

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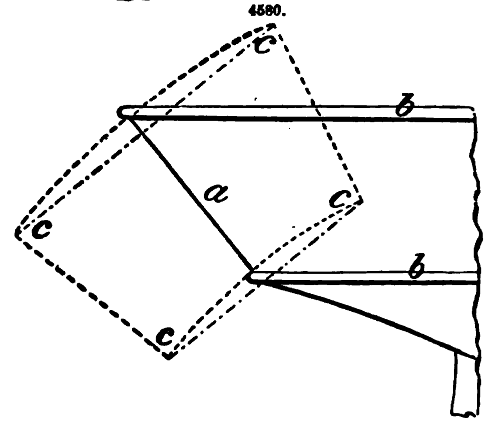

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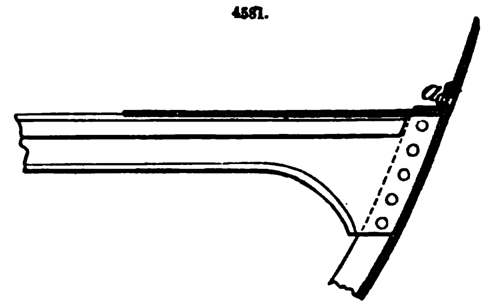

Have the inside strakes stitched at the butt-straps and frames, say about six rivets in each butt-strap and two in each frame, before putting on the outside strakes.

The filling-plates at the bulkheads at back of shell-plates should be at least the width of the fore-and-aft flange of the frame angle-iron longer than two spaces of frames, in the fore-and-aft peake bulkheads the filling-plates will be about 3 in. longer on account of the set and bend.

In the plating round the knuckle of stern, see that the plates are kept up to the sheer-marks, and on no account have them below, and allow a clear 1¼ in. from top of rivet-hole to the edge of plate.

In taking off the dimensions to order plates for going round the stern, supposing them to be of average size, an allowance of about 5 in. should be made beyond what the plate measures in the depth of the stern. In Fig. 4580, *a* is the centre of plate; *b b*, mouldings; *c c c*, development of plate, showing allowance.

In marking the rivet-holes for sheerstrakes aft, attention should be paid to having the holes for connecting the stringer-plate to the shell of the vessel high enough up for the rivet-hole to come in the centre of the flange of the angle-iron, Fig. 4581. *a*, see that this rivet is not too low in bosom of angle-iron.

In the plating of topgallant forecastles, the plate that is cut for the knightheads should project, say, about 3 in. beyond the knighthead bulkhead, and the rivets through the bulkhead should be flush on the forward side. The projection is to allow for bolting on the knee-brackets, and so on.

4582.

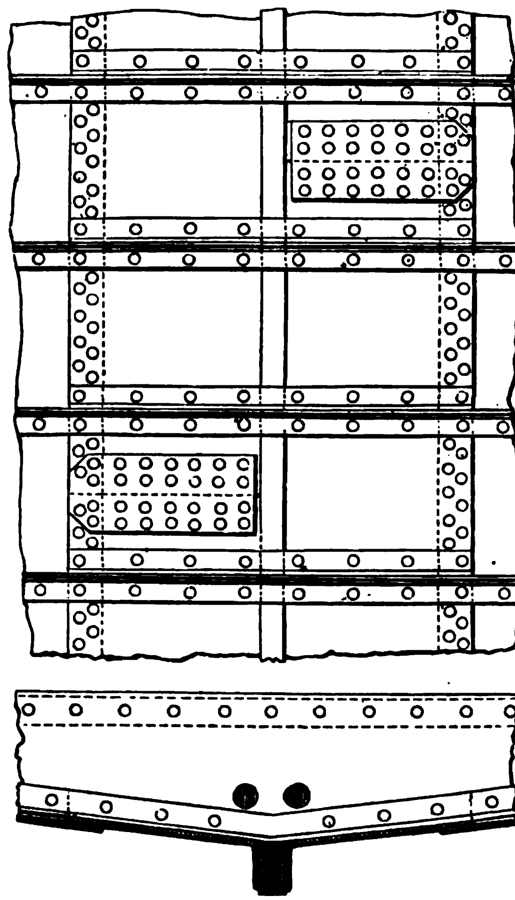

Fig. 4582 is a sketch showing a good arrangement of rivets in frames, heel-pieces, and butt-straps of garboard strake.

Books upon Iron Shipbuilding:—Taylerson (R.) 'On Building Iron Ships,' 8vo, 1854. Russell (J. Scott), 'The Modern System of Naval Architecture,' 3 vols., folio, 1865. Fairbairn (W.), 'Treatise on Iron Shipbuilding,' 8vo, 1865. Freminville (A.), 'Traité Pratique de Construction Navale,' royal 8vo, and plates in folio, Paris, 1865. Rankine (Professor), 'Shipbuilding—Theoretical and Practical,' folio, 1866. Lissignol (E.), 'Navires en Fer à Voiles,' royal 8vo, Paris, 1866. Grantham (J.), 'Iron Shipbuilding, with Practical Illustrations,' 12mo, with plates in 4to, 1868. Reed (E. J.), 'Shipbuilding in Iron and Steel,' 8vo, 1869. Smith (T.), 'Handbook of Iron Shipbuilding,' 12mo, 1869. 'Transactions of the Institution of Naval Architects,' edited by E. J. Reed, 4to, 1860 to 1872. 'Lloyd's Rules for Building Ships,' 4to, 1872.

IRRIGATION. Fr., *Irrigation;* Ger., *Berieselung-Bewässerung;* Ital., *Irrigazione;* Span. *Riego.*

Irrigation is either natural or artificial. The former depends upon rain, upon wells, and upon the flooding of rivers. The latter is conducted by means of canals and tanks.

Canals are divided into two great classes, those of irrigation and navigation. The conditions required to develop one of the former class successfully are, that it should be carried at as high a level as possible, so as to have sufficient fall to irrigate the land for a considerable distance on both sides of it; and that it should be a running stream so as to be fed by continuous supplies of water from the parent river, to compensate for that consumed in irrigating the lands.

The conditions of the latter are, on the contrary, that it should be a still-water canal, so that navigation may be equally easy in both directions; and as no water is consumed except by evaporation or absorption, and at points of transfer from a higher to a lower level, the required quantity of fresh supply is comparatively small, and it is thus most economically constructed at a low level. An irrigation canal, however, may and should be laid out so as to serve for navigation as well; the velocity of the stream being made as gentle as is consistent with its primary uses, so as to afford facilities for boats ascending against it as easily as possible.

There may be said to be two distinct systems of canal irrigation pursued at present in the north and south of India, which may be called the Bengal and Madras systems, respectively. The difference between the two arises from the physical peculiarities of each country.

The Madras system has been confined to the Deltas of the great rivers, such as the Godavery and Kistnah, and consists in throwing a dam across the bed of the river to raise the surface level of the water, which is then conducted along canals, whose mouths are in rear of the dam, to the lands requiring it. This system is not applicable to lands at a high level above the surface of the river, as it would be impossible to raise the water sufficiently to overflow them. It is therefore confined to alluvial tracts, which have been formed by deposits from rivers in a state of flood.

Nearly all great rivers are thus charged with silt during the rains. In the upper part of their course, where the natural fall of the country is great, and the velocity of the stream high, this silt is carried forward by the water holding it in suspense, and the action of the stream is generally erosive, and tends to lower the bed; but as the river reaches the plains below, the velocity gradually diminishes, and at last falls below that necessary to carry on the silt, which thus becomes deposited. The effect of this is to raise their beds and cause them to be constantly shifting their course, and also to raise the ground on both sides of their banks often for a considerable width by successive deposits of silt when they overflow their banks. Thus, such rivers will

not run in the lowest lines of the valleys, as in ordinary cases, but there will often be a considerable fall from their banks outwards. It is evident this gives great facilities for such irrigation works as are above described.

But in the rivers of Northern India, although there is a certain width of land on each side which has been formed as above, yet it is, in general, a very narrow strip. The greater portion consists of a high table land occupying nearly the whole extent of the country between the two rivers, and, in general, rising very abruptly from the land on each side. It is impossible to irrigate this high land by a short cut from the river; the depth of digging would be too great, and the water would never stand at a sufficiently high level to be brought on to the land except by expensive apparatus for raising it. It is necessary to go back to a point high up in the river's course, whence the water can be brought on to the high land by excavation of a moderate depth, and by which sufficient command of level may be obtained to overflow the surface.

The simplest kinds of canals used in India are known as inundation canals. Cuts are made from the river inland, for a certain distance, and are then carried in a direction generally parallel to the fall of the country, or the course of the river. By these, when the latter is in flood, the autumn crop is watered. But in the cold season, when the water is low, the levels do not admit of the land being irrigated, and the spring crop thus derives no benefit from these canals, which have then run dry as the river is low. During that time of year labourers are employed to clear the canal beds of the silt which was left by the waters in the summer; in India often as much as 6 ft. in depth will accumulate at the mouth in one season. The irrigation is usually carried on by means of branch canals leading from the main one, whence the water is carried by minor channels on to the fields. But sometimes, when the levels do not admit of surface irrigation, the water is raised from the canal itself by the Persian wheel, or a temporary dam is placed across the channel to raise the level.

The weirs in use for canals in the river Ebro are usually from 6 to 9 ft. high, and are very primitively constructed, being formed of rough blocks of stone thrown loosely together. Often as much as 50 per cent. of all the water coming down the river filters through them, and the expense of keeping them in order is very great, for in times of flood they always get damaged. In the small Spanish rivers the weirs are of small height; they are formed by driving two rows of piles or strong stakes from 3 to 4 ft. apart, and filling the space between them with sods, brushwood, and stones from the bed of the river; and, despite their temporary nature, they resist with great tenacity the floods which come down with considerable velocity in these rapid streams.

On the river Ganges weirs of a simple character are adopted which answer their purpose well. The work is carried on by means of a barge attached to a strong hawser, stretched across the river, and firmly fixed at both ends. On this barge a derrick and windlass is fitted up, and by these the materials are lowered into position. Triangular frames formed of poles about 18 ft. long, firmly spiked together, are placed vertically, with the apex down-stream, about 15 ft. apart. The poles lying on the bed of the river are crossed by rough poles and boulder-stones thrown upon them; by these they are kept in place. Again poles are spiked across the upper part of the frames, and the whole filled with boulders. The water is thus dammed back, though a great deal escapes, and the difference of level between the water on the upper and the lower sides of the weir is about 3 ft.; the depth of water being about 12 ft. above the weir, and 9 ft. below it. At a short distance lower down a similar weir is erected.

There are no works at the head to control the supply of water, for the course of the river is so uncertain, that it may completely desert the head, and the water may have to be brought in by a new mouth excavated for that season, which, again, may be useless in the next, or the bank of the river may be cut away to such an extent as to involve the head works in its fall. Under any circumstance, there is always a considerable deposit of silt at the head, which would naturally be increased by anything in the shape of a dam.

The silt excavated from the bed during the cold season is usually heaped up close to the edge in rough spoil banks, and is constantly falling in, while the tortuous course of the channel also causes large deposits of silt at the bends. The accumulation is still further increased by the water having no exit at the tail of the canal, which usually terminates in a series of small channels in the middle of the district. The labour of clearance thus becomes a heavy annual charge or drawback on the benefits received from the water, and the numerous deserted channels in various parts of the country show that without such labour these canals would soon silt up and become useless.

Canals of Permanent Supply.—The source is generally a river carrying a perennial stream, and the head of the canal must be located high up on the river's course, so as to obtain plenty of command of level, and get on to the high ground without much heavy digging; generally for this purpose it is necessary to go either to the spot at which the river finally leaves the hills, or to a point not far below that spot. At this point the water, except in freshets, is pure and free from silt, the great enemy of canals, and the course of the river is restricted within narrow limits, so that by dams thrown across the river bed, the water can be easily diverted into the new channel.

The quantity of water required is determined partly by the area of land to be irrigated, and partly by the quantity of water that can be obtained from the river when at its lowest.

It is evident that the effective work of a cubic foot of water discharged from the canal, for irrigating the land, must depend upon variable data, such as the nature of the soil, and the crop, the distance the water has to be carried on to the land from the main channel, the humidity of the atmosphere, &c.

The average assumed for drawing out the projects for the Baree Doab and Ganges canals, derived from data afforded by the Jumna canals, was, that each cubic foot a second of discharge was capable of actually irrigating 218 acres; and reckoning that for each acre actually watered there would be two other acres either lying fallow or being watered from wells or rain, then each cubic foot would represent 654 acres (say one square mile) of culturable land more or less dependent

on the canal. In the Soane Canal project (1861) Colonel Dickens reckoned three-fourths of a cubic foot of water a second for every square mile of gross area.

If the canal is to be a navigable one, a certain minimum depth must be assumed everywhere, so that the amount of water required for that minimum must be allowed over and above the quantity to be expended on irrigation.

A large area of the land through which the canal takes its course may be unfit for cultivation. The soil may be bad or swampy, or it may be reserved for forest or grass preserves, or occupied by towns or cantonments. All this has to be taken into consideration in fixing the area actually available for irrigation, whence the amount of water required must be determined.

The proportion of depth to width on the Western Jumna Canal, being that which the stream has in course of years formed for itself, was found by a series of trials to be about 1 in 13. On the Baree Doab Canal, the proportion fixed in construction was 1 in 15; for the Sutlej Canal, 1 in 14. It is evident, if the canal is to be navigable, that the minimum of width must always be sufficient to allow of two boats passing each other, while a minimum of depth, usually 2½ ft., must also be allowed to float the boats.

The side slopes of the canal channel will be arranged generally according to facilities for excavation, for unless the slopes are made very flat, or are turfed at a great expense, the action of the water will in ordinary soil quickly cut them to the shape at which they will ultimately stand firm.

Having determined the quantity of water, and fixed the proportion of depth to width, and a minimum for both, chiefly with reference to navigation facilities, there remains to be determined the slope of the bed. If this slope is too great, the bed of the canal will be torn up, and the foundations of all bridges and other works will be endangered. Besides which, the difficulties of navigation against the stream will be largely increased. If, on the other hand, it is too small, a larger section of channel will be required to discharge a given quantity of water, and many additional works, such as falls or locks, will be required; there will also be danger of silt being deposited in the bed, or of the stream being choked by the growth of aquatic plants.

It is therefore necessary to avoid both extremes; but it is not always easy to do so, and in general a compromise has to be made. Moreover, as the velocity increases very rapidly with the depth, it is evident that a slope of bed which might be a very proper one for water of a certain depth, would be too great if it were necessary to increase that depth so as to throw an extra supply into the canal.

The minimum velocity required to prevent the deposit of silt or the growth of aquatic plants is about 1½ ft. a second, so that if a minimum of depth be fixed, we can find the minimum of slope necessary to secure any given discharge. Under ordinary circumstances this may be fixed at 6 in. a mile, though it is occasionally even lower than that.

The maximum is not, however, so easily fixed. It must in the first place vary with the nature of the soil of the bed. A stony bed will stand a velocity of 3 ft. a second, while sand will be disturbed by a velocity of 6 in. Again, the maximum velocity at which a boat can be navigated against the current at a profit is evidently a very intricate problem, depending on such varying data as the moving power employed, whether steam, animals, or men, the description of boat, value of the cargo, and so on. In some experiments made on the Ganges Canal it was found that at a velocity of 3·76 ft. a second the water just ceased to cut away the bank, and slightly deposited silt. With the ordinary soil of the plains, and taking everything into consideration, 3 ft. a second may be taken in India as a safe maximum velocity for these canals.

The upper part of the Baree Doab Canal has a fall of 4·2 ft. a mile over a bed of shingle and clay, but navigation at that point was not required.

The Ganges Canal starts with a fall of 2 ft. a mile, which soon diminishes to 1·25 ft., and this latter may be said to be its ruling gradient. With a depth of water not exceeding 5 ft., this gives a very manageable velocity both as regards the safety of the works and the navigation down stream. For up-stream navigation it would be advantageous to reduce it. But when 6, 7, or 8 ft. of water are thrown into this canal, the velocity due to the above fall is doubtless too high.

In the Sutlej Canal project, Captain Crofton fixed upon 2½ ft. as his minimum depth of water at full supply, and arranged his declivities of bed so that the calculated mean velocity of current should in no case much exceed 3 ft. a second.

For the Soane canals, the velocity has also been fixed at about 3 ft. a second (two miles an hour), the side slopes being 1½ to 1, and a bottom width equal to the depth plus one, squared, in feet.

From the above considerations, therefore, we can determine the section of the canal channel by the help of proper formulas. See Canal.

The section of the water-channel and slope of the bed being determined, it is evident that the surface of the water may either be within soil, that is, below the natural surface of the ground, or above soil, when it will have to be retained by artificial embankments. If not merely the surface level, but the whole body of water is above soil, the embankments must be very massive, and may require to be puddled to render them water-tight. In the great Solani embankment the water is retained within a solid masonry revetment on each side backed up by an earthen bank averaging 16 ft. high and 40 ft. thick.

Although the water being thus raised above soil greatly increases the facility of irrigation by its command of level, the construction of such embankments involves great expense, and if any breach occurs, the damage done will be very great.

The most favourable conditions are when the canal water is partly within and partly above soil, that the earth excavated from the channel just suffices to build up the banks, while there is sufficient command of level for all irrigating purposes; and the nearer this can be approximated to, the more perfect will the canal be.

For sanitary reasons it may be desirable to keep the water, as a general rule, within soil; but the effect of this will be to increase greatly the cost of the canal; and if, as is often the case,

a sandy stratum underlies the superficial clay, it is very undesirable to dig down to the former, as much water may thus be wasted by leakage and absorption.

Alignment of the Canal.—The steps to be taken in fixing the line of the projected canal, and in marking it out when approved of, are similar to those described in the article on ROADS. The gradients have to be duly considered in both cases, though much more carefully in the former. The requirements of the different towns and villages, which, in the case of a road, have to be considered with reference to traffic, will have chiefly to be viewed in regard to irrigation, and secondarily only for traffic in the case of a canal.

The obstacles to be avoided, whether mountain torrents, swamps, or hills, are much the same, and the more elaborate methods of overcoming them required for canals will be described farther on.

If no good map of the country exist, one must be made. The next step will be to get a series of cross-sections of the country to be irrigated, from river to river, by means of lines of levels, from one to five miles apart, and having a direction at right angles to the watershed or supposed watershed; these are connected by lines carried along the river banks. The country being thus covered with a network of levels all reduced to the same datum line, and marked down on the map, the general line of watershed along which it is desirable as far as possible to carry the canal will at once be evident. This line, cutting the cross-sections nearly at right angles, should then be carefully levelled as a trial line, as well as any other alternative line that may present itself; and on this the general project will be based. The actual construction of the line will be similar to that of a road, but the curves must be made as flat as possible and very carefully rounded, or the action of the water will cut away the banks on one side and cause a deposit of silt on the other.

The cuttings are laid out and made like road cuttings, but the embankments must be different, as they have to retain within them a large body of water. Their thickness must therefore be very great on both sides of the water channel, and they vary in mean width from 30 to 100 ft., according to the depth of water. If leakage occurs, they must have a wall of puddle, or be otherwise rendered water-tight.

The considerations which determine the site of the canal-head have already been noticed. The canal should be made to tail into a river or reservoir, into which the surplus water unexpended will be discharged; and in order to secure an efficient scour, it will be advisable slightly to increase the velocity at the end. A fall into the river is generally the best way of effecting this.

The points at which branches should be taken off from the main line, as well as the general course of these branches, will be fixed from a due consideration of the levels of the country and the extent of culturable land requiring irrigation. If the main canal has been carried on or close to the watershed or backbone of the district, then the branches should be lined out as far as possible on the minor ridges which lie on both sides of the main ridge, the object in every case being to keep a sufficient command of level for surface irrigation. There is a further reason for carrying the canal channels on watersheds wherever possible, namely, to ensure the minimum of interference with the country drainage, and to ensure an efficient scour at the tail of the channel. The size of the branch channels and slope of their beds will be dependent on the same principles as those already noted in the case of the main line, and the same remark applies to the village water-courses which are led off from the main and branch lines, and from which it is now the most approved practice to deliver the water for the actual irrigation, its further employment being left to the cultivators.

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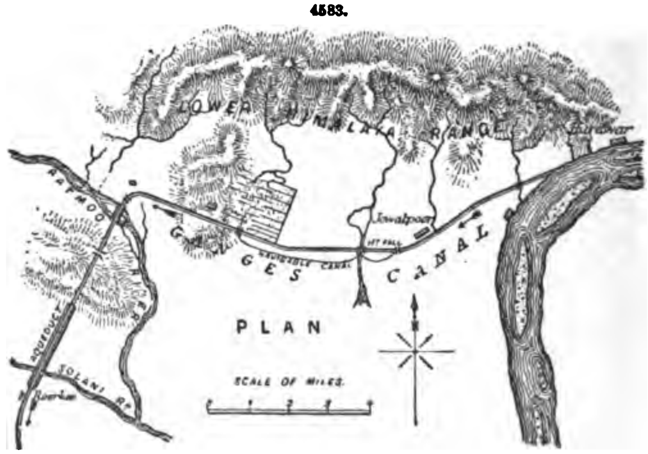

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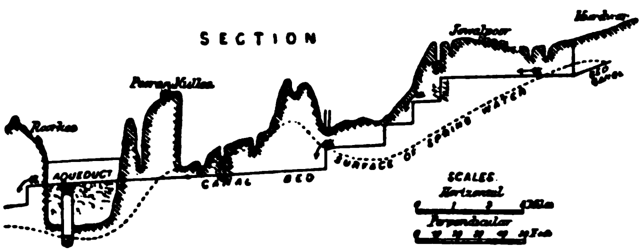

Bridges of communication are required wherever roads cross the canal, and for the general convenience of the country. On the Ganges Canal they were designed at about every three miles, and

when in the vicinity of large villages are provided with ghâts or steps for convenience of bathing. Care should be taken to provide sufficient headway under the arches or openings for laden boats to pass easily when the canal has its full supply. On the Soane canals 13 ft. are allowed for this purpose; and it is also desirable that the obstruction to the stream presented by the piers should be as small as possible. For this reason it will generally be advisable to widen the canal slightly at these points, so as to allow a full water-way for the stream through the bridge. Otherwise expensive precautions have to be taken to secure the foundations; and the increased velocity under the arches will render navigation dangerous or at least difficult.

A tow-path should be provided on at least one side of the canal at a constant level of 1 to 2 ft. above the water surface. It may be from 12 to 15 ft. wide in earthen section, and not less than 6 ft. under bridges; the tow-paths should be carried under the side arches of bridges, in no case through the abutments or wing-walls, the latter arrangement being an obstacle to free navigation.

A road is also desirable on one side of the canal for convenience of inspection. It may be 20 ft. wide and planted with trees. Tree plantations are also general along the canals of the N.W. provinces. No trees should, however, be allowed within 30 ft. of the water's edge, as their proximity interferes with the stability of the embankments.

Stations for the engineers and overseers employed on the line are also provided at intervals, and are generally fixed at the sites of the most important works.

Falls, Rapids, and Locks.—So long as the slope given to the bed of the canal is the same as the natural fall of the country through which the canal is excavated, the level of its bed will remain at a uniform depth below the surface of the ground. But although this can generally be managed in flat plains, throughout the greater portion of their length, yet in the upper portion of the canal the slope of the ground is very much greater than that which it would be proper to give to the canal bed, and peculiar arrangements have to be made to compensate for this difference of slope. Figs. 4583, 4584, illustrate the northern division of the Ganges Canal. The section, Fig. 4584, will show how this excess of fall has to be overcome, by laying out the canal bed in a series of steps, so as to keep it at a tolerably uniform level below the surface of the country, until the flat country is reached, where the slope is the same as that proper for the canal.

The points where the bed is let down from a higher to a lower step are called falls. Their

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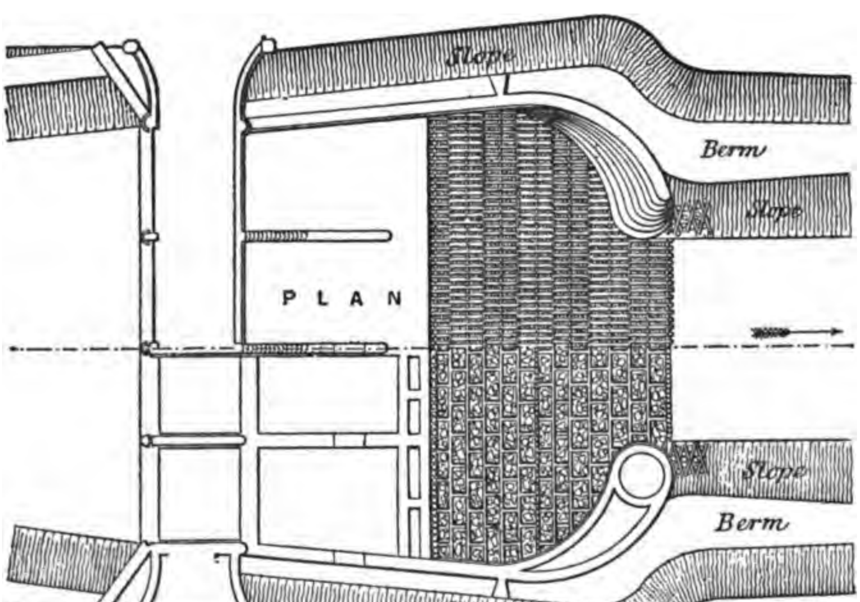

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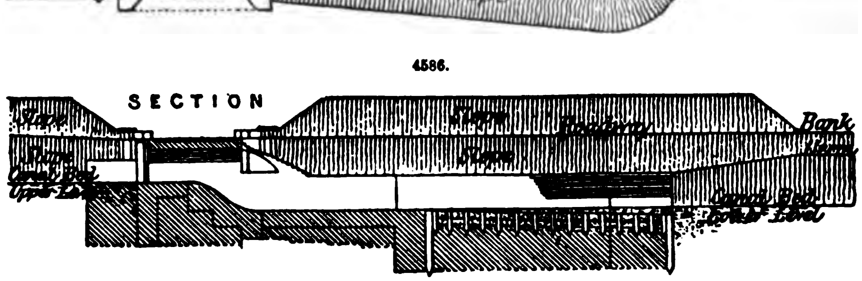

location should be near the places where the canal bed, if continued without a break, would have to be carried in embankment above the surface of the country; their exact position is generally made to coincide with the requirements of a bridge or some other masonry work.

It is evident that the fall must be of some more durable material than earth to resist the action of the water tumbling down the height of the step, and masonry is therefore employed. The bed of the canal has also to be protected by a masonry flooring from the plunging action of the water, and the banks must be revetted for a considerable distance below. The exact shape of the fall itself is a point on which there is much difference of opinion. Ogee falls, Figs. 4585, 4586, were employed by Sir P. Cautley, on the Ganges Canal, with the idea of delivering the water at the foot of the fall as quietly as possible. On the Baree Doab Canal, vertical falls, Figs. 4587 to 4589, are used, the water being received at the bottom into a cistern sunk below the level of the flooring, which thus forms an elastic cushion to receive the shock, instead of opposing a dead resistance to its force; while the accelerated velocity of the falling water in a forward direction is also checked. The action of the water is still further lessened by making it play over a wooden grating, by which it is divided into a number of filaments or threads, on the same principle as the rose of a common watering pot.

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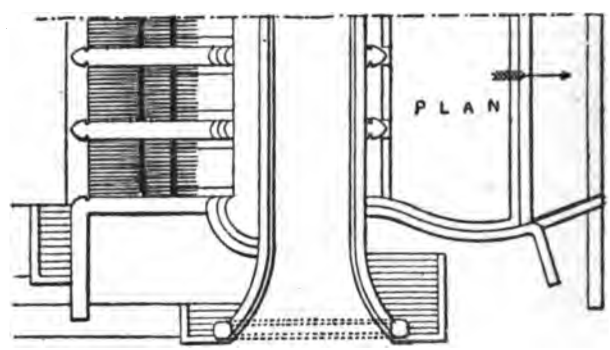

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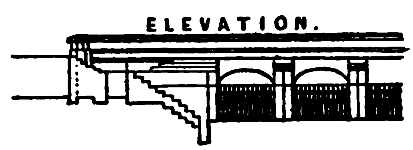

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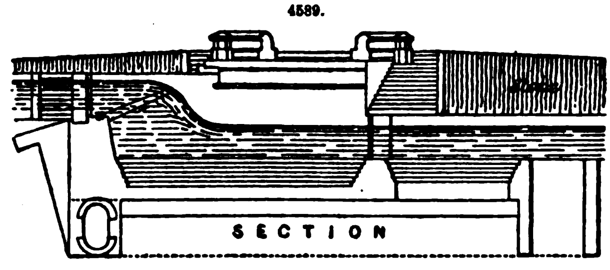

The very dangerous scouring and cutting action of a large body of water falling over a height of even a few feet, must be seen to be fully appreciated. The greater the height of the falls and the depth of water, the more violent, of course, will be the action; those on the Ganges Canal are not higher than 8 ft.; but with 6 ft. or more of water going over, the action is most severe, and nothing but the very best masonry is capable of resisting it. If stone can be obtained, it should always be used; if not, none but the hardest bricks must be employed, laid in an unyielding foundation with fine mortar joints; the banks must be revetted with masonry for a considerable distance down stream, and the bed of the canal protected by a solid masonry flooring, the tail of which is defended by a row of sheet piling. The fall should be divided into distinct chambers, which can be laid dry, one by one, for the sake of repairs, without stopping the canal. On the Ganges Canal the masonry flooring is continued to the end of the chamber, beyond which crib-work of dry boulders is employed as far as the end of the revetment walls.

The effect of a fall occurring at the end of a canal reach, is to increase the velocity and diminish the depth of the water for a considerable distance above the fall. This increase and diminution are gradual from the point where this action commences down to the fall itself, where they attain a maximum, so that the depth of water passing over the fall is very much less, as the velocity is very much greater, than the normal depth and velocity above. This increase of velocity before the water reaches the fall produces a dangerous scour on the bed and banks of the canal; and in order to guard against this, it has been found necessary to head up the water at the falls on the Ganges Canal by means of sleepers dropped in the grooves of the piers. It has also been proposed to narrow the falls, so as to produce the same effect. Either of these ways is probably cheaper, though less effective, than protecting the beds and banks of the canal channel by artificial means a sufficient distance above the fall; but without thus raising the crest of the fall this protection would have to be extended for something like a mile above in order to be efficient.

The violent action of the water at the foot of the fall, having a momentum due not only to its vertical height, but also to the depth of water going over it, can only be guarded against by employing the best and hardest materials available to receive the shock of the water, and by the efficiency of the tail revetments.

The wearing action of a large body of water under the above circumstances falling incessantly upon masonry, however strong and well built, is so constant a source of anxiety and danger in spite

of all precautions, that many methods have been devised for accomplishing the necessary change of level in other ways.

Rapids, Figs. 4590 to 4592, have been employed with success on the Baree Doab Canal; the fall is laid out on a long slope, 15 to 1, instead of by a single drop; the slope being paved with boulders, laid without cement, and confined by walls of masonry in cement, at intervals of 40 ft. both longitudinally and across stream. The longer the slope the more gentle is, of course, the action of the water, but the greater also is the quantity of masonry employed. In general, the choice between the two is a mere question of expense and material available. On the above-mentioned canal rapids were adopted wherever boulders were procurable at moderate cost.

Rapids and falls interfere with navigation, and where this must be uninterrupted a system of *barrage* or of *locks* must be provided.

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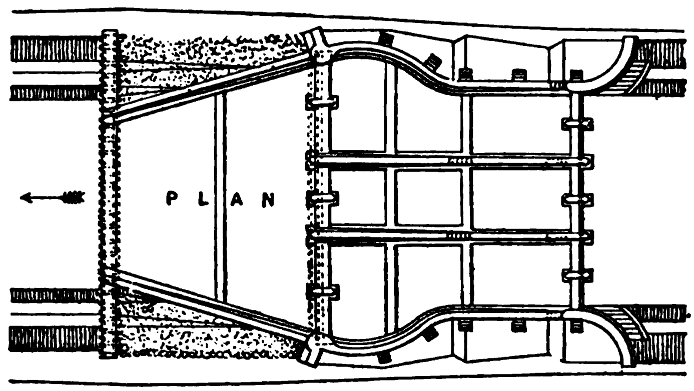

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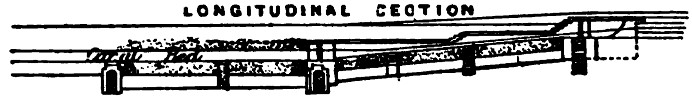
LONGITUDINAL SECTION



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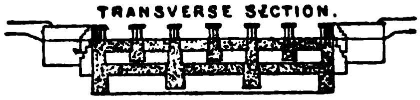
TRANSVERSE SECTION.



Headworks, Dams, and Regulators.—The works at the head consist essentially of a dam across the river, by which the water is held up and checked in its onward flow, and a regulator across the head of the canal channel by which the proper quantity of water is admitted.

In most cases the canal is taken out of a branch of the main river, and the permanent dam is thrown across the branch only, the water being diverted from the main stream into the branch by temporary dams constructed of boulders, which are swept away on the rise of the river, and are annually replaced.

Dams are either made solid, when they are called weirs, or they may be provided with openings.

The advantage of the weir is that it is self-acting, requiring no establishment to work it, and if properly made ought to cost little for repair. It is also a stronger construction, better able to withstand shocks from floating timbers and other obstructions. Its disadvantages are that its first cost is generally greater, and that it causes a great accumulation of silt above it, and interferes far more than an open dam with the normal regimen of river. It is possible that in certain cases this might result in forcing the whole or part of the river water to seek another channel, and the possibility of this should always be taken into account; but if the river has no other channel down which it could force its way, the accumulation of material above the weir would be an advantage rather than otherwise, as adding to its strength. The advantage claimed for the open dam is that the interference with the normal action of the river is reduced to a minimum, the strong scour obtained by opening its gates effectually preventing any accumulation of silt above; its first cost too is generally smaller than that of a weir.

A dam consists of a series of piers at regular intervals apart, on a masonry flooring carried right across and flush with the river bed, protected from erosive action by curtain walls of masonry up and down stream.

The piers are grooved for the reception of sleepers or stout planks, by lowering or raising which the water passing down the river is kept under control. The intervals between the piers are generally 10 ft., which is a manageable length for the sleepers. If the river is navigable at the head one or two 20-ft. openings fitted with gates must be provided to enable boats to pass.

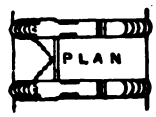
The flooring must be carried well into the banks of the river on both sides, to prevent the ends of the dam being turned; and the banks and bed of the river will generally require to be artificially protected for some distance, above and below the dam, to stand the violent action of the water when the gates are partially closed.

The two flanks of the dam for some length are generally built as weirs, that is, instead of piers and gates the masonry is carried up solid to a certain height, so that when the water rises above that height it may flow over the top of it. The advantage of this arrangement is that it affords an escape for water in case of a sudden flood when the dam may be closed, while when the water is low it is kept in the centre of the river and away from the flanks, and thereby causes a more perfect scour.

When the river is subject to sudden and violent floods, damage might be done before the sleepers could be all raised one by one; it is better therefore to employ flood or drop gates, Figs. 4593, 4594, in such a case, that is, gates which turn upon hinges in the piers at the level of the flooring, and which when shut are held up by chains against the force of the water. In case of flood the chains are loosened, the gates drop down, and the water flows over them. Should the intervals between the piers be over 10 ft. there would be a difficulty in hauling the gates up again.

4593.

4594.



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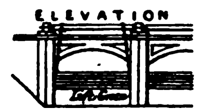

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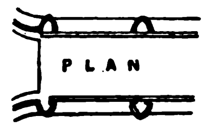


A bridge of communication may be made between the piers of the dam if required. But as it is not desirable to have it obstructed with traffic, it may be merely a light foot-bridge, or the intervals may be spanned temporarily with spare sleepers.

The dam and regulator are generally close together and connected by a line of revetment wall.

The regulator, Figs. 4595, 4596, like the dam consists of grooved piers resting on a firm foundation carried across the canal bed. As floods are made to escape down the river, and are shut out from the canal, drop-gates will not be necessary for the regulator, and the water may be admitted and controlled either by planks alone or, as is usual, by a gate moving up and down in the grooves, on to which planks can be dropped when necessary one by one. The gates are raised or lowered by a windlass and chains; the windlass may be movable, or one may be fixed between every two piers and worked by handspikes.

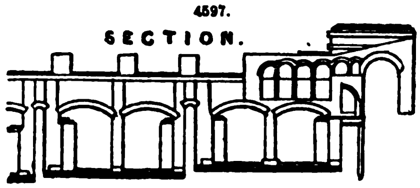
The piers of the regulator are generally connected by arches, so as to form a regular bridge of communication across the canal.

The bed and banks must be defended by masonry, as in the case of the dam, so as to be safe from the water's action when the gates are partially closed.

The flooring of the regulator at the head of a canal is a convenient datum for all the canal levels. A water-gauge should be fixed on it at one of the piers, so that the amount of water passing into the canal may be accurately known.

The above description may be understood to apply to all regulators employed on the canal, as well as to the one at the head. Thus there will be a double regulating head where each branch is taken off, one regulator being fixed across the head of the branch line to admit the necessary amount of water which the branch is calculated to hold, and the other being built across the main channel at the same spot. By the simultaneous working of the two it is evident that the water will be thoroughly controlled.

4597.



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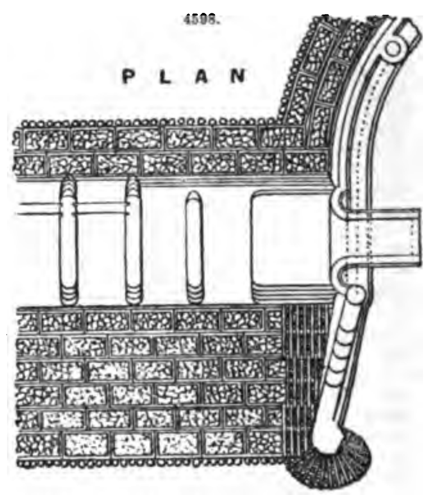

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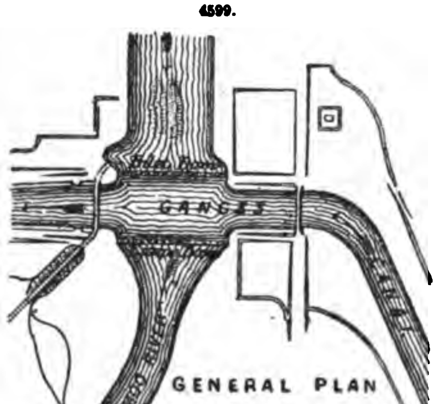
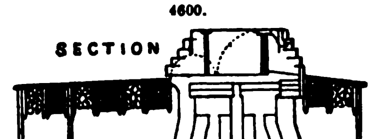


4600.



Regulators of smaller size will also be required at the head of each principal water-course, where it is taken off from the main line for irrigating purposes. A single opening will generally

be enough, and gates sliding up and down in the grooves of the abutments may be worked by a ratchet and lever or a windlass with spokes.

But in order to establish a complete control over the water in the canal channel, provision must be made for any excess which may arise from sudden rain floods or from the water not being always required for irrigation. This is effected by means of escapes, which are short cuts from the canal to a river or other natural water-course into which the excess of water can be discharged. Figs. 4597 to 4600 are sections and plans of the escape dam, flank, and works at Dhunowree, on the line of the Ganges Canal; the number of openings in the dam is forty-seven, of which five on each flank are arranged as ogee falls, and the remainder are provided with drop-gates. Escapes should be provided at certain intervals all the way down the line, and a double regulating head should be built at the point where the escape is taken off, as in the case of a branch canal. On the Ganges Canal they were projected at about every forty miles, but much must depend on the convenience with which they can be made, that is, on the proximity of the canal to the river or water-course into which the escape is to be conducted. They should also, if possible, be provided at all dangerous points, such as above a long line of heavy embankment, where, in case of the bank bursting, great damage would ensue. The cut should be made large enough, and with sufficient fall, to carry off the whole body of water that can reach that point, so that, if necessary, the canal below the escape may be at any time laid dry for repairs, without stopping its running above, by opening the escape regulator and shutting down the corresponding one across the canal. By this means also that part of the canal above the escape may be opened when completed, while work on the lower portion can proceed.

Drainage Works, Aqueducts, Inlets, and Superpassages.—These are an important class of works by which the canal is carried over the various obstacles to be met with in its course.

If the line of a torrent cannot be diverted, there are three cases under which it may have to be crossed. 1st, when it is on a lower level than the canal; 2nd, when on the same level; 3rd, when it is on a higher.

In the first case, when the torrent or drainage line is on a lower level, the canal is carried over it on an aqueduct. The valley drained by the torrent will be embanked across in the usual way, care being taken that sufficient water-way is provided under the aqueduct for the torrent to pass when in flood.

The second case is where the torrent is crossed on the same level. It may be a small drainage channel only occasionally filled, or at least never bringing down but a small body of water. In that case it simply becomes an inlet, and is provided for by an arched opening through the embankment by which the water can be passed into the canal. In this way all mere surface drainage is provided for at various convenient points, though as the course of the canal when once clear of the difficult ground above lies close to the watershed of the country, the amount of intercepted drainage is small.

But if the torrent is of large dimensions and bringing down a great volume of water at a high velocity, the above method will not answer; the water loaded with silt would choke up the canal bed, and its force would destroy the embankments and do irretrievable damage. More elaborate arrangements have therefore to be made.

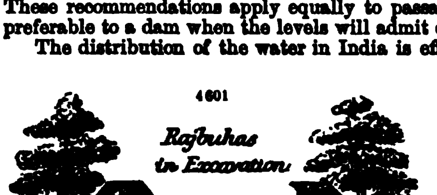
A regulating bridge is placed across the canal channel provided with the usual sluice-gates. A dam is built across the channel of the torrent provided with flood-gates. Under ordinary circumstances the dam is closed and the regulating bridge is open, so that the canal water flows along as usual. But when the torrent is in flood, then the dam must be open and the bridge closed, so that the flood water may cross the canal and run down its own channel. The bed of the torrent below the dam must be paved for a certain length to prevent erosion, and the sides of canal and torrent have to be revetted for a considerable length to prevent their being cut away by the water.

The third case is where the torrent crosses on a higher level, when it has to be carried over on an aqueduct, generally called in that case a superpassage, to distinguish it from the first case, where the canal flows over the torrent. This becomes a very expensive and troublesome work, as a large water channel has to be allowed to carry any extraordinary flood over the canal in safety, and sufficient headway must be allowed under the superpassage so as not to interrupt the navigation.

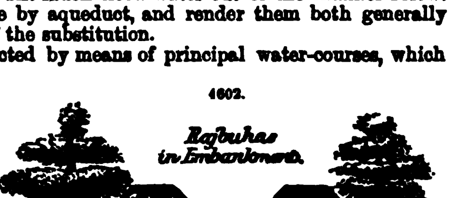
It possesses, however, the great advantage of keeping the canal completely free from any influx of flood water from the torrents, which is always more or less heavily charged with silt. It has the additional recommendation of not requiring the maintenance of a large establishment every rainy season, as in the case of a level crossing, where the regulating apparatus must be worked by manual labour; and lastly, the canal supply can thus be kept up uninterruptedly, there being no necessity to shut it off at the crossing to keep the silt-laden flood water out of the channel below. These recommendations apply equally to passage by aqueduct, and render them both generally preferable to a dam when the levels will admit of the substitution.

The distribution of the water in India is effected by means of principal water-courses, which

4601



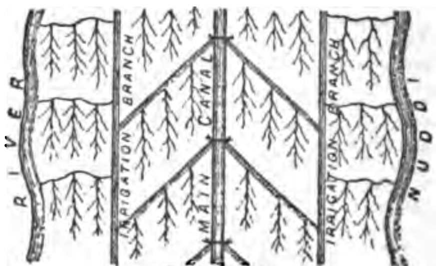
4602.



are small branch canals with a masonry regulator at the head, from which the cultivators make their own water-courses to their fields. Figs. 4601, 4602, are of water-courses, termed in India

Rajbuhas, in excavation and in embankment, and Figs. 4603, 4604, general arrangement of canal and water-courses. On the elder canals irrigation is carried on from the main channel itself, but the inconveniences arising from this practice were found in India to be so great that it has been generally discontinued.

4603.



P L A N

4604.

S E C T I O N

The water-courses, constructed on the most approved system, form a continuous line of irrigating channel on each side of the main canal, and generally parallel to it. This line is fed by cuts from the main canal at regular intervals, say three miles apart, and in these cuts are fixed the heads of irrigation of all the village water-courses which are made by the villagers themselves.

The canals recently constructed in Spain under the superintendence of J. F. Bateman and George Higgin, one to irrigate the valley of the Henares, in the provinces of Madrid and Guadalajara, the other to irrigate the valley of the Esla, in the provinces of Leon and Zamora, are instructive examples of the modern system of irrigation. From Higgin's account of the construction of these canals, recorded in the Trans. Inst. C. E., vol. xxvii., we extract the following particulars;—

The river Henares takes its rise amongst the mountains of the Somo Sierra, and after running for a length of ninety-six miles falls into the Jarama not far from Madrid. Its course is extremely steep, and the current very rapid. The total fall of the river from the weir of the new canal to Alcalá, a distance of thirty-six miles, is 407 ft., giving a mean fall a mile of 11·3 ft. The geological formation of the valley is the upper tertiary. It forms a portion of a vast hollow basin, the edges of which are cretacean. The total length of the new canal is 46¼ kilomètres, or twenty-eight miles. It takes its water from the river at a point sixteen miles above Guadalajara, just below the junction of the Sorbe and Henares, and ends at Alcalá. The total area of ground embraced by the canal is 12,400 hectares, = 30,628 acres. Of this amount, however, some portion cannot be irrigated, and after deducting this, and that due to roads, streams, towns, &c., there remain about 11,000 hectares, say 27,170 acres of ground capable of irrigation. For this purpose the volume of water conceded by Government is 5 cubic mètres a second, = 175 cub. ft., for nine months, from October to June inclusive, and 3 cubic mètres a second, or 105 cub. ft., for the remaining three months. From accurate measurements made near the new weir since the commencement of the works, it appears that during the months of July, August, and September, the average quantity of water carried by the river is 210 cub. ft. a second, the lowest point which it has touched being 140 cub. ft. a second. During the remainder of the year it carries an average of 300 or 400 cub. ft. a second. It is subject, however, to enormous floods, which come down with great rapidity; and in designing the new weir it was necessary to provide for the floods. Several came down during the progress of the works, some of which were estimated to be carrying 8000 cub. ft. a second. The weir, it is calculated, will discharge 20,000 cub. ft. a second, which is more than in all likelihood it can ever be called upon to do.

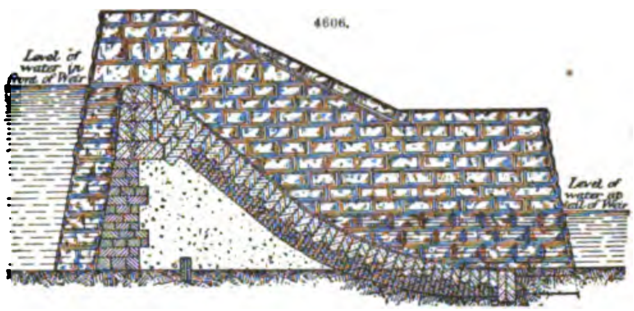
The preliminary operations were commenced on the 1st January, 1863. The most difficult portion of the canal is comprised in the first ten kilomètres. Immediately after leaving the river, the canal runs into a heavy rock cutting, 2500 mètres long, and with an average depth of 16 ft. At 2780 mètres from its commencement the canal reached the most difficult portion of its course, a high limestone cliff, which overhangs the river. In the original plans it had been proposed to carry the canal in a covered way along the débris in front of this cliff, but a slight examination showed that it would be impossible to do this with safety, and it was at once decided to tunnel the cliff. This tunnel has a total length of 2900 mètres, = 3171 yds., and at its exit a further length of 300 mètres of deep cutting in gravel had to be carried between walls. At the ninth kilomètre the canal crosses the Madrid and Saragossa Railway, and at the tenth kilomètre a wide torrent bed, known in the country as an arroyo, had to be crossed. This and the railway crossing were the binding points in this section of the canal; and it was with reference to them that the height of the new weir was fixed.

The site chosen for the new weir was the only one where a good foundation could be expected. Fig. 4605 shows a cross-section on the axis of the weir. The bed of the river was composed of compact clay rock, very impermeable, mixed with strata of excessively hard conglomerate. The crest of the weir was at an average of 6 mètres above the river bed; but on the right bank, where the river channel ran, it was considerably deeper. Fig. 4606, a cross-section of the weir as constructed. The front wall, to a height of $2^{m}\cdot 50$ below the crest of the weir, was built of rubble in hydraulic mortar, the foundation being benched into the rock, which was blasted for the purpose. The main body of the weir was of hydraulic concrete, the apron being faced with cut stone blocks, 2 ft. deep and 1 ft. thick, every fifth row being a bond 3 ft. deep and 1 ft. thick. The toe of the weir was formed by two stones, 3 ft. 6 in. deep and 1 ft. thick, let 3 ft. into the solid rock, and from this sprang the apron. From the top of the rubble wall to the crest the weir was entirely of cut stone. Three courses 2 ft. high, and one course 2 ft. 4 in. high, carried it up to the due level. The lower course of stones were immense blocks, measuring 5 ft. on the bed, 2 ft. high, and never less than 3 ft. 3 in. on the face. They were cut with a check, upon which the succeeding course rested, and V joints were cut in every face, and were run in with pure cement after the

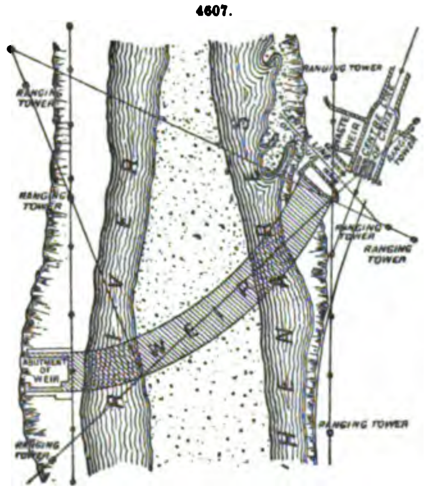
stone was in its place. The back portion of these stones was filled with cut stone, carefully jointed to fit exactly into the places, and the whole when completed formed a perfectly impermeable mass of cut stone. For the purpose of guarding against filtration, a continuous line of cut stone was let into the rock in the centre of the concrete. These stones were 2 ft. deep, one half being sunk in the rock and one half rising up into the concrete. They were all bedded in pure cement, and were cut with V joints, also run in with cement. Fig. 4607 shows the form of the weir on plan. It is composed of two curves, one of 121 mètres radius, and the smaller one of 60½ mètres radius. The abutments were founded upon the rock in a similar manner to the weir, and were built of large blocks of rock-faced ashlar in courses 50 centimètres high.

4605.

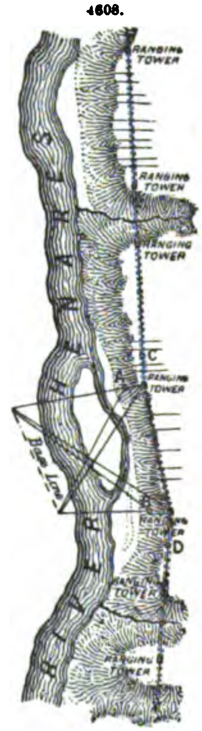
4606.



4607.



4608.



The water for the canal is drawn off by five sluices. These are set in masonry arches of the same class of work as the abutments. At the entrance of the canal there are three sluices, for the purpose of scouring out any deposits which may accumulate in front of the gates. The sill of these sluices is 1 ft. lower than those of the canal sluices, these latter being 5 ft. under the crest of the weir. Immediately inside the head sluices, and forming a portion of the head works, an overflow weir, 12 mètres wide, is built, in order to provide for the discharge of any waters which a sudden flood might admit into the canal during the absence of the guard. This is necessary, as floods have been known to come down so quickly in this river as to carry away women who were washing on the banks.

The river, at the time of the commencement of the work, ran in two channels; one close to the left bank, which was shallow and carried very little water; the other, which was the principal channel, ran close to the right bank. The work was begun on the left bank, and carried forward until close upon the deep channel, a gap being left in the weir near the left side of the river. When the work arrived at the deep channel, the river was turned by throwing a bank across it at some distance above the weir, and the foundations of the right bank were then put in. The weir is 120 mètres long, = 130 yds., between the abutments.

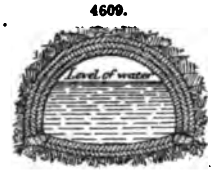
The hydraulic concrete used was in the proportion of 5 of lime, 9 of sand, and 22 of gravel or broken stone. It set very hard, made an excellent job, and withstood successfully the tremendous floods that sometimes swept over it during the construction of the work.

The construction of the tunnel offered no engineering difficulties. About one-half of it was in a stiff, tenacious clay, the remainder being in limestone rock. It was found necessary to line the whole with brick, as the rock, though hard when first cut, crumbled under exposure to air and water. Fig. 4608 shows the general position of about one-half the tunnel. At 240 mètres from the commencement it crossed a torrent bed, the level of the top of the tunnel being slightly under the bed of the torrent. Two points of attack were thus obtained running in almost on the level. At 900 mètres farther on the same thing occurred; and at 4580 mètres the tunnel ran into the side of the hill, and a portion, 220 mètres in length, was able to be constructed by open excavation. In addition to these natural faces, seven galleries were run in from the side of the cliff, so that there were in all twenty-two faces; and the work could consequently be quickly pushed on. In most cases a shaft was sunk from the top to meet the gallery, for the purpose of preserving the line of the tunnel. In the case of the two galleries, however, shown on Fig. 4608 and marked A and B,

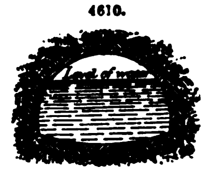
this was not done, it being determined to run these in by triangulation. For this purpose a base line was selected on the opposite side of the river, and being carefully measured, the distances by triangulation were obtained from the centres of the two towers fixed on the top of the cliff over the line of the tunnel. The direction of the galleries was then given from the measured base, and a stone, with an iron centre let into it, was sunk at the entrance of each gallery, and the distance of these points being again found by another measurement, the distance between this and the first calculated distance gave the length of the gallery to the centre of the tunnel. When this point was reached, the measured angle upon the base was set off, and the work was commenced upon all four faces. About 70 or 80 mètres were driven in this way, the tunnel being taken out for its full width. As, however, a long distance had to be driven before meeting the next faces, and it was considered inadvisable to drive a heading on account of the small size of the tunnel and consequent extra cost, it was thought that the risk of going on upon the calculated lines was too great, as a slight error, either in the measured base or in the angles, would have created a large error in the lines of the work. A couple of shafts were accordingly sunk at the points marked C and D, when, to the satisfaction of all concerned, the new lines dropped from the surface were found to coincide almost exactly with those given by the triangulation.

The section of the tunnel and the different thicknesses of arching are shown in Figs. 4609 to 4611. The whole of the brickwork was set in hydraulic mortar. As it was found, however that

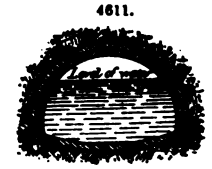
4609.



4610.



4611.

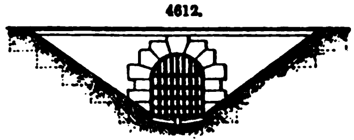


the pure lime and sand set too quickly, the custom of the country was followed, and a percentage of white lime was mixed with the hydraulic, the proportion being 1 part of hydraulic, 1 part of white lime, and 4 parts of sand. This mortar was longer in setting than the pure mortar, and gave much better results. It cannot be used where the work is liable to be immediately covered with water; in the tunnel this was not the case.

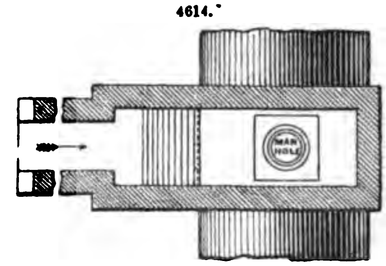
The clear diameter of the tunnel inside is $3^{m}\cdot 40$, and its height $2^{m}\cdot 22$. It was finished on the 30th May, 1866, a year before the weir. Air-shafts were left at three of the faces where the tunnel came out near the surface, and four of the galleries were bricked in, so that easy admission might be had to the tunnel at any time, Figs. 4612 to 4614. The remainder of the galleries and shafts were filled in.

The only other works of importance on this canal are an aqueduct over the Arroyo Tejada at the entrance of the tunnel, the bridge under the railway, and the bridge over the Arroyo Majanar.

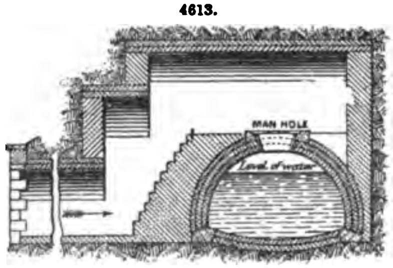
4612.



4614.



4613.



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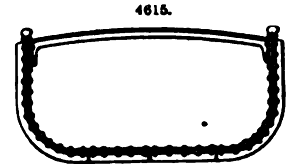


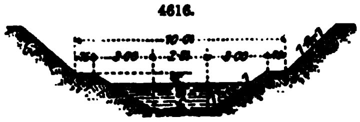
The difficulties presented by the bridge under the railway were simply those caused by the work having to be carried on without disturbing the passage of the trains. This was done by shifting the line and building one-half of the abutments at a time. The railway was carried on wrought-iron girders sent out from England. In consequence of the little headway which could be obtained over the Torrent Majanar, it became necessary either to carry the canal over by a tube or under by a siphon. It was resolved to adopt the former plan, and the canal is carried over in a wrought-iron tube of 20 mètres, say 65·6 ft. span, Fig. 4615. The joint of this tube with the masonry was made as follows;—A strip of 7 lb. lead was bolted securely to the end flange. The lower end of this lead was fixed in a channel cut in the stone, and run with a mixture of pitch, tar, and sand. The sides were completed in the same way. By this means the tube can change slightly by contraction or expansion without risk of leakage. In addition to this joint, the tube rests on a flannel pillow soaked in tallow, and the side flange was packed with oakum and tallow.

There was thus a double joint. This tube was the last thing done. It was immediately filled with water to the depth of 5 ft., and has since been kept full. It is perfectly tight, both at the joints with the masonry and in the other parts. With a load of 93 tons of water it sank ½ in. in the centre. At the side of this tube are three sluices for discharging the canal if necessary.

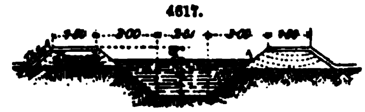
The remaining works on this canal are not of much importance, the only considerable one being an aqueduct over the Arroyo Dueñas, consisting of two arches 20 ft. span each, with a height from the bed of the Arroyo to the coping of the canal of 26 ft. The approach to this bridge is rather heavy, the bank containing 32,000 cub. yds. A good deal of difficulty is experienced in Spain in works of this class, from the exceptional character of the streams and water-ways. The rainfall in most parts of Spain is irregular, and large quantities fall within a few hours. Thus, in the month of May, showers will frequently fall in Madrid almost tropical in volume, to be succeeded by three or four months of nearly perfect dryness. From the denuded nature of the country, and the absence of any species of herbage, the rain runs off with great rapidity: every depression becomes for the time being a torrent, and it is necessary to provide for their discharge. As they all bring down large quantities of gravel, it is not possible to pass them into the canal; and for the same reason it is dangerous to pass them under the canal, unless a free discharge can be made for them at the lower side. In cases where this was difficult, and the nature of the ground permitted it, these streams are carried over the canal by means of small iron tubes, Fig. 4615. In the Esla Valley, where the extreme flatness of the ground, and the absence of any defined water-courses, render it difficult to pass the streams under, the greater portion of them are passed over the canal in this manner. In many cases the country roads become torrent-beds in time of rain, and provision has to be made for both kinds of passes. These were variously treated, according to circumstances. In some instances headway was obtained by altering the canal section to a wide, shallow bed; in others, the canal itself was passed under by means of a masonry siphon. In all the works of the canal economy was sought, as far as was compatible with good workmanship. The greater portion of the ordinary roads were passed over by small timber bridges. Where the roads were of more importance, brick bridges were constructed. All works under the water-line were built in hydraulic mortar; above that line, in white mortar. All arches, both above and below the water-line, were turned in cement. At all the mill-falls sluice-gates are provided on the main line of the canal, the fall having a slope of 2 to 1; it is paved with cut stone 9 in. deep, laid in hydraulic mortar on a bed of concrete 18 in. thick. The water is measured out to the mills over an iron weir similar to the system adopted for the measuring of the irrigation water. One hundred litres a second, falling 1 mètre, is taken as an effective horse-power. This is equivalent to about 44,000 lbs. lifted 1 foot high in a minute. The banks where the canal ran above the ground were made of well-selected earth, rammed in layers about 6 in. thick, and each layer thoroughly soaked with water.

The sections adopted for the first division of the canal are shown in Figs. 4616, 4617. The inside and outside slopes are 1½ to 1, and the banks are $1^m \cdot 80$, = 6 ft., wide on the top.

4616.



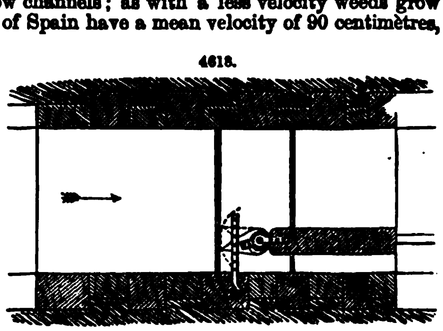
4617.



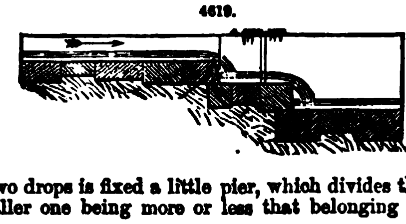
The depth of water in the first few divisions is $1^m \cdot 50$, = 5 ft., and the velocity adopted was 70 centimètres, say 2 ft. 4 in. a second. This is rather high, but it is a matter of importance in Spain to avoid exposing the water in wide shallow channels; as with a less velocity weeds grow freely. Many of the old canals and water-courses of Spain have a mean velocity of 90 centimètres, or 3 ft. a second.

As to the best method of measuring the water to be supplied to the landowners. In the old Moorish works no actual measure of water was attempted in the sense at present understood. The quantity of water in the river or canal was divided proportionally over the lands irrigated: if the river brought more water, each canal received more; if less, less. Some of their systems for dividing the water were sufficiently ingenious. The system adopted at Elche was that used by the Moors before their expulsion from the country. The quantity of water in the river is divided into twelve equal portions, each of these portions being called a hilo de agua, the "hilo" being the twelfth portion of the river running for twenty-four hours. These are sold every morning by public auction, and the prices they fetch are almost incredible. The system by which the proper proportion of water is taken off for each canal is shown on Figs. 4618, 4619. The water is conducted along a level masonry channel with a very slow velocity, till it falls over a drop. At a distance of 1 mètre farther on it falls over another drop. In the intermediate space between these two drops is fixed a little pier, which divides the breadth of the channel into two portions, the smaller one being more or less that belonging to

4618.



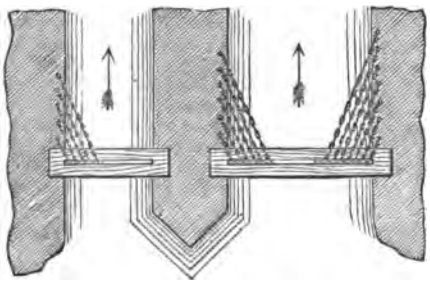
4619.



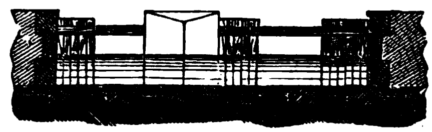
the canal for which the water has to be taken. The point of this pier consists of a movable vane, terminating in a sharp edge, which, when it is in a straight line with the pier, almost touches the first drop. It is evident that by moving this arm, the sheet of water flowing over the drop can be divided within certain limits with considerable accuracy. After every sale the person in charge of the distribution goes round and fixes these arms, allowing to each channel the proportion of water which corresponds to it; and thus they remain for twenty-four hours, until the next sale takes place, and a new division becomes necessary.

Figs. 4620 to 4622 show the method of dividing the waters in Lorca. In this case the space through which the water passes is divided into the number of proportional parts or hilos supposed

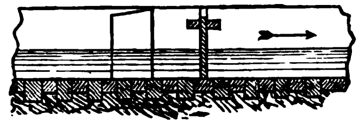
4620.



4621.



4622.

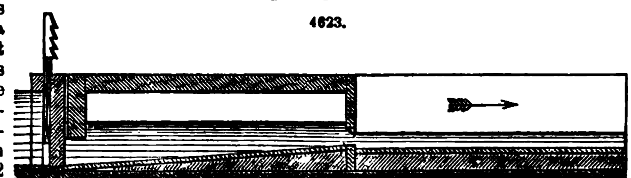


to be in the river. At the left-hand side is the opening through which flows the water which it is proposed to take off for the secondary channel. Both these openings are capable of being closed by small vertical bars of wood, which drop into a channel cut into the masonry below, and are held at the top by two iron bars. There are exactly as many of these wooden bars as there are hilos in the stream; if, for instance, the main stream carries twenty-four hilos, and it is necessary to take ten off for the secondary channel, fourteen of the wooden bars are taken out of the principal channel and ten out of the side one. It is manifest that as a measure of water this is open to many objections, but it is ingenious and interesting when it is considered that it has been in use probably upwards of eight hundred years.

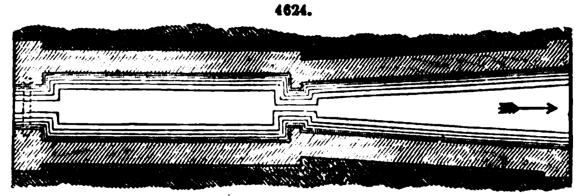
The principal objects to be sought in a module are, simplicity of arrangement of the different parts, freedom from friction or any similar deranging cause, constant discharge under varying heads, and, of course, an exact measure of quantity. It is of great importance that there should be no concealed machinery, not only from its liability to derangement, but because there is then so much more liability to an alteration in the discharge, without its being noticed by the guard. It is also of importance to have, if possible, such a measure as can be easily inspected by the land-holders, in order that each man may, if he pleases, satisfy himself that the proper quantity of water is flowing into his channel.

The Milanese module, Figs. 4623, 4624, is perhaps the one best known. The principle of this module is that of discharging the water through a certain opening under a constant head. For this purpose a unit of measure was fixed on, called the "oncia magistrale," which is that quantity of water which flows freely under the sole influence of pressure through a rectangular opening having a uniform height of 7·86 English inches, a breadth of 4·12 English inches, and a constant head above the upper edge of the outlet of 3·93 English inches. The water is admitted from the main canal by a sluice into the first chamber, which, according to law, ought to have a length of at least 20 ft., in order to deaden the flow of the water. The floor of this chamber is inclined from the sluice up to the outlet,

4623.



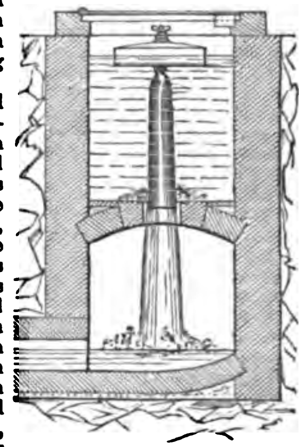
4624.



and in some cases a covering of planks or slabs, called the cielo morto, is placed across the chamber at the regulation height. It is the guard's duty to see that the water in this chamber does not rise above the height; and for this purpose he is charged with the key of the sluice. The outlet is cut in a slab of stone, edged frequently with iron. It is evident that if this aperture were cut in a thin plate, if the head of water were constant, and if it arrived at the aperture in a state of stillness, a result as nearly exact as possible could be obtained. In practice, however, it is not very accurate; the outlet given above being assumed as a unit, any number of "oncias" are supposed to be given by merely increasing the width of the opening by the required number of oncias; and it is supposed that this will give a simple multiple of the first unit.

This is not, however, the case. By the addition to the width of the opening, the discharge increases more than a certain number of units; thus, an opening of the width of six oncias discharges much more than six separate openings of one oncia each. The water arrives also with too much velocity at the aperture, as the dimensions required to diminish it and the other points are never strictly observed; and the result is, that while the Milanese module possesses some of the elements required in a good module—simplicity of arrangement and facility for examination both by the guard and by the people interested in the irrigation —it is erroneous in its construction, and does not give unvarying discharges.

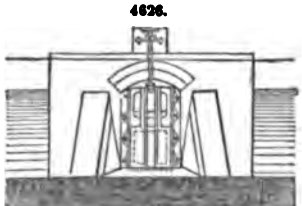
4625.



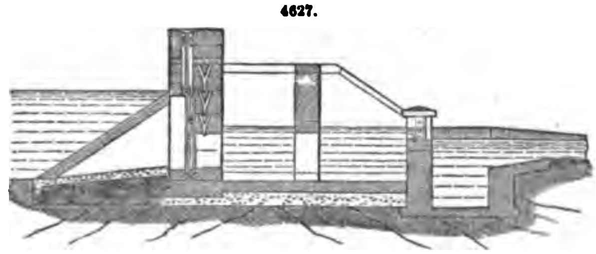
On the Marseilles Canal, water is measured by being allowed to fall into a tube which passes through the bottom of the water-chamber. This tube, being attached to a float, rises and falls with the water, and preserves the mouth of the tube at a fixed level below the surface. In practice this does not work well, as it is almost impossible to preserve free working of the tube in the bottom plate, and at the same time to avoid leakages. This plan, however, has suggested to Ribera the most ingenious module which has perhaps yet been devised, Fig. 4625. A chamber is constructed at one side of the canal, into which the water is admitted through a screen. In the floor of this chamber is fixed a wrought-iron plate, having in it a circular hole of a given diameter. Into this hole hangs a pendulum of parabolic form suspended by a float, the water escaping in the space left between the pendulum and the orifice. The dimensions of the pendulum being accurately calculated, it is evident that with the rise or fall of the water a greater or less opening is left for the discharge, which can therefore be kept constant under all heads. This module is entirely free from most of the objections that the others are open to. There is no friction of parts, no liability to derangement, and the discharge is made under one of the few conditions in which it is believed water can be accurately measured. The only objections to it are, the loss of head and the disturbance that might result from the deposit of mud on the floor of the chamber, in which case the orifice would assume a trumpet form. As most of the rivers in Spain bring down large quantities of mud in suspension, this objection might have some force.

The module adopted on the Henares and the Esla canals, Figs. 4626 to 4629, cannot lay claim to novelty; but it is believed it will fulfil its purpose practically. The water is merely measured by

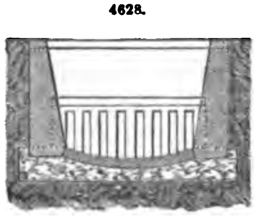
4626.



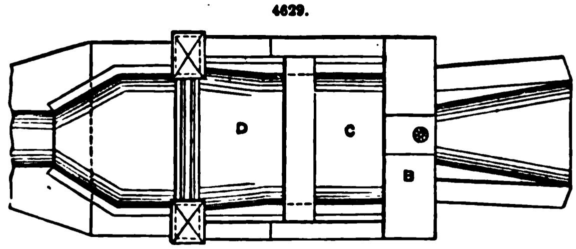
4627.



4628.



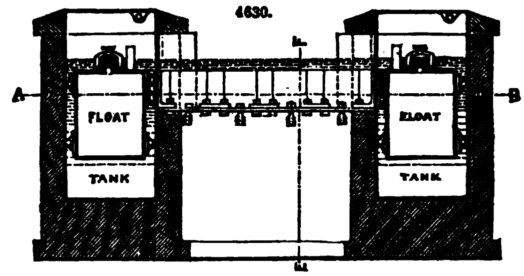
4629.



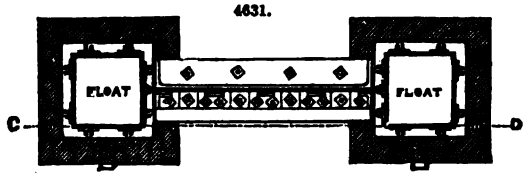
being discharged over a knife-edged iron weir. The water is admitted from the main canal by a sluice working in the division wall B. After entering from the canal, the water passes into the first chamber C, and from thence into the second chamber D, where the weir is fixed. The communication between the two chambers is made through narrow slits, and the water arrives at the weir without any perceptible velocity, and perfectly still. The weirs vary from 1 mètre to 2 mètres in breadth, according to the quantity of water required to be passed over. On the wall of the outer chamber is fixed a scale, with its zero point at the level of the weir edge, and by means of this scale any person can satisfy himself that the proper dotation of water is flowing into the distribution channel. By managing the sluice, the guard can regulate to a nicety the height of water to be passed over the weir. This module has several good points. The system of measurement is that which possesses the most fixed rules in hydraulics, and gives the most constant results; it is simple, and almost incapable of derangement; it will serve equally well for turbid waters as for clear

ones; it can take off the waters with the least possible loss of head, a most important point in canals such as the Esla, where the loss of a few feet of headway would prevent the irrigation of many thousand acres. The guard can see at a glance whether the proper amount of water is passing into the course, and the irrigators can satisfy themselves on the same point. The only reasonable objection to this module is that any sudden variation in the head of water in the canal will affect the discharge, which will continue to be greater or less than it ought to be according to circumstances, until the guard comes round again. This is undoubtedly true; and to meet this objection it was at one time proposed to use a movable weir suspended from floats working inside the pillars, which would rise and fall with the water, and preserve the crest of the weir at an invariable level below, Figs. 4630 to 4632. On reconsideration, however, it was determined not to put this in, as in most well-regulated canals there is never likely to be any perceptible variation in the head of water. There is generally a guard in charge of the head-works, whose special duty it is to see that a constant body of water is admitted into the canal. If the river is flooded, he must close the gates; if it diminishes, he must open them. The water taken off from the canal for the different water-courses is a fixed quantity, and that passed on to the lower portion is therefore likewise invariable. The only cause of a sudden change of head would be in the case of a sudden and heavy fall of rain; but to provide against this, at every two or three kilomètres there is a waste weir, which would immediately carry off the surplus waters; and even if a little more was discharged through the module for a short time, no inconvenience would result from this. On the whole, as a practical working module, that adopted for the Henares and the Esla canals is probably as good as can be wished for. Experiments are now being made to ascertain the proper coefficient for these weirs under varying heads.

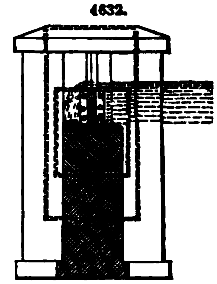
4630.



4631.



4632.



As regards the probable losses by filtration and evaporation, it is difficult to arrive at any reliable calculation. Ribera estimates, from experiments made on the Isabel II. Canal, that the total loss from both causes will be only 2 per cent. of the whole body of water carried. This appears low, but it must be borne in mind that the whole of this canal is to be lined with masonry. Nadault de Buffon gives the average percentage on canals as 15 per cent. of the total volume carried. He does not mention under what circumstances such a percentage may be expected. Now, it is quite evident that any estimate for filtration must be expressed in terms of the wetted border and depth or pressure of water, and no general rule can be arrived at that will apply to all kinds of canals. Experiments are being made on the Henares Canal to ascertain the loss by filtration in ordinary earth under varying depths, with a view to obtain more precise data. The evaporation in Madrid, according to the returns of the Royal Observatory for the year 1867, was as follows;—

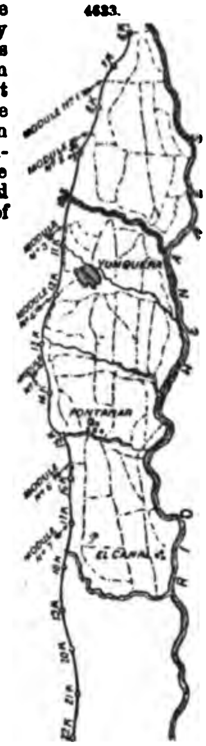
	Inches.		Inches.
January	1½	Brought over	28¾
February	2	July	13½
March	3	August	11
April	5¼	September	6
May	6¾	October	3¾
June	10¼	November	1½
		December	½
Carried over	28¾		
		Total	65

The total amount of water evaporated from the Henares Canal during the month of July would be 99,042 cubic mètres, which would be equivalent to nearly ¾ per cent. on the total amount of water carried.

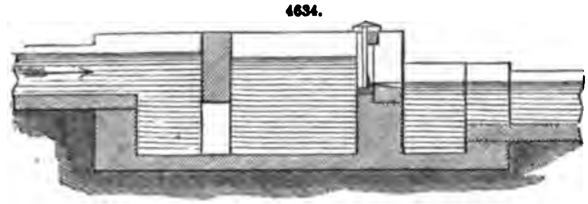
Another important point to the irrigation engineer is the principle to be followed in the distribution of the waters. Fig. 4633 represents a portion of the valley of the Henares now under irrigation. The system of distribution is shown by the dotted lines. It is divided into portions of about 300 or 350 hectares, say 750 to 850 acres, each of these plots being served by one of the primary channels, taken off direct from the main canal. On this primary channel at its point of departure from the main canal is fixed one of the modules before described, and by this module the dotation of water necessary for that area of ground is measured. Thus, for 300 hectares the dotation would be $300 \times \cdot 45 = 135$ litres a second. In cases where the water is distributed by

the company amongst a number of small proprietors, it is done in this way: the total amount of water is passed into each of the secondary channels, and irrigation begins on the plot at either end of the channel. By means of the company's survey and register, the acreage of every plot in the valley is known; it is only necessary therefore to calculate the number of minutes or hours the stream must run to give a certain quantity of water, and give the distributor his book with the names of the proprietors in their order and the hours that each must have the water. After the stream has run for the time allotted to it, it is shut off and turned on to the next field; and so on until all the fields depending on that secondary channel are irrigated. The stream is then shut off that secondary channel and turned on to the next in turn; and so on until all are irrigated, and the first is commenced again. In some instances the larger proprietors have wished to take into their own hands the distribution of the water upon their estates; and in these cases the module, Figs. 4634, 4635, has been used. Its mode of

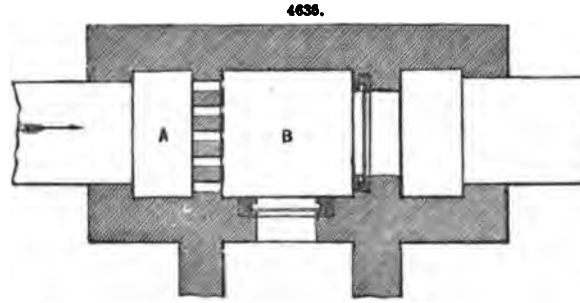
4633.



4634.



4635.



working is as follows;—Suppose the primary channel to be conveying 150 litres a second, and that one of the larger proprietors wishes for a dotation of 50 litres a second into his own channel. The water of the primary channel is passed into the chamber A, from whence it passes through divisions in the party-wall into B, where it arrives in a state of almost perfect stillness. This chamber has two openings—one which is a continuation of the main primary channel, and the other which leads to the secondary channel. These openings are provided with weirs of sheet iron, and over these the water discharges. It is only necessary to proportion the width of the weirs to the amount they have each to discharge, and as the head is the same for both, they will each discharge their proportionate parts. Thus, roughly speaking, in the case under consideration, the weir on the secondary channel would require to be one-half the width of that on the primary channel. See Aqueduct. Barrage. Canal. Locks and Lock-gates. Weirs.

List of Books on Irrigation:—Keelhoff (J.), 'Traité Pratique de l'Irrigation des Prairies,' 2 vols., 8vo, Bruxelles, 1856. Moncrieff (C. C. Scott), 'Irrigation in Southern Europe,' 8vo, 1868. 'Memoria sobre el Reigo de los campos de Madrid con las Aguas del Rio Loxoya,' por Don Juan de Ribera, royal 8vo, Madrid, 1866. Roberts (J. P.), 'Irrigation in Spain,' 8vo, 1867. Parato (R.), 'Irrigation et Assainissement de Terres,' 4 vols., 12mo, and 4to Atlas, Paris, 1851. 'Madras Irrigation Reports,' folio, 1866 to 1872. Gibbs (J.), 'Cotton Cultivation,' crown 8vo, 1862. R. Baird Smith, 'Italian Irrigation,' 2 vols., 8vo, and Atlas in folio, 1855; 'Irrigation in the Madras Provinces,' 8vo, 1856. Nadault de Buffon, 'Des Canaux d'Irrigation de l'Italie Septentrionale,' 2 vols., 8vo, and Atlas in 4to, Paris, 1861. Maurice Aymard, 'Irrigations du Midi de l'Espagne,' 8vo and folio, Paris, 1864. See also Belidor, 'Architecture Hydraulique;' Sganzin, 'Cours de Construction;' Sir P. T. Cautley's 'Report on the Ganges Canal,' and numerous Papers in the Minutes of the Institution of Civil Engineers; 'L'Annals des Ponts et Chaussées,' and the 'Professional Papers on Indian Engineering,' edited by Col. Medley, R.E., Roorkee, 1863 to 1872.

ISOMORPHISM. Fr., *Isomorphisme*; Ger., *Isomorphismus*.

Certain substances possess the property of crystallizing in identical or nearly identical forms, and of giving, when they together assume the solid state, homogeneous crystals in which these substances are contained in any proportions. This property received from Mitscherlich the name of *isomorphism*.

The labours of Haüy had already shown that every substance susceptible of crystallization possesses a particular form distinct from those of all others; the only exception being the forms of the cubic type which Haüy considered as *limiting* forms beyond the influence of the general law. This proposition, in its geometrical rigour, remains true even now, for *isomorphous* substances, often showing the greatest similarity in the most minute particulars of their crystallization, are derived

from primitive forms, the angles of which are not identical, and which angles may differ by several degrees. But at the time when Mitscherlich made his important discovery, the crystalline forms of various substances chemically different were regarded as absolutely identical. It was supposed that these substances were compounds in which one of the components possessed such energy to crystallize that it impressed its own form upon all the others. Mitscherlich began by attributing to isomorphous substances angles absolutely equal. Wollaston, however, had shown by exact measurements that calcite, sidero-calcite, and dolomite do not possess the same angles. Mitscherlich's experiments, made upon the phosphates and arseniates, led him to the conclusion that it is not identity, but extreme similarity of form, and especially that physico-chemical property of crystallizing together in indefinite proportions, that constitutes isomorphism. Isomorphism, governed by analogies in properties and formula, that is, in constitution, is therefore above all a physical property. From this point of view especially it offers deep interest to the chemist, who many a time has been able to infer, from a reason dependent on isomorphism, a similarity of constitution, and not only to correct certain formulas, but to enrich science with new substances, such, for example, as the compounds of vanadium.

The researches of Mitscherlich had been preceded by a number of isolated observations which, one would think, ought to have attracted more notice from chemists and mineralogists. Werner had already pointed out the resemblance in form between pyromorphite and apatite. Leblanc had discovered that a solution of ferrous sulphate, to which sulphate of copper has been added, deposits crystals which, with the form of the sulphate of copper, contain variable and often very considerable quantities of sulphate of iron. A similar observation had been made by Beudant and others respecting the sulphates of iron and zinc. Vauquelin had shown that ammonia may replace potassa in any proportion in alum without changing the form of it; and Gay-Lussac, having suspended a crystal of alum of potassa in a solution saturated with alum of ammonia, saw it increase regularly as if it had been placed in its mother-lye. These facts remained isolated in science until Mitscherlich, profoundly struck with the idea that an identical crystalline form must correspond to a similar atomic grouping, studied from this point of view various series of salts. He soon discovered that the sulphates of the different metals of the magnesian series were capable of crystallizing with the same number of molecules of water and presenting similar forms, that they could combine with the sulphates of ammonia or potassa and give identical crystals, that the arseniates and the phosphates, corresponding to the sulphates, offered the same analogy of crystallization, and that in general the nature of the constituent atoms seems to have infinitely less influence upon the crystalline form than their grouping. Still he was obliged to attribute to the chemical nature of isomorphous substances the cause of the slight difference in angle, which an accurate measurement of the crystals compelled him to acknowledge. From the time of Mitscherlich's labours the notion of isomorphism became an exact one; and later researches have not modified it in any important degree.

A remarkable character of isomorphous substances has recently been discovered by Gernez. He has shown that a sursaturated solution crystallizes equally well when touched with a crystal of the substance dissolved or with an isomorphous crystal. Lecoq de Boisbaudran has even succeeded by this artifice in obtaining crystallized hydrates which do not form in the ordinary conditions of crystallization.

Certain natural and artificial crystallized substances have very nearly the same angles and great similarity of form, though belonging to two different types. Such are albite and felspar, the group of the mesotypes, augite and bronzite, augite and rhodonite, bitartrate of potassa and that of ammonia. Laurent was the first to regard these substances as isomorphous, and to this particular isomorphism he gave the name of *paramorphism*. This chemist remarked this curious fact, namely, that in two crystals of different but similar composition certain angles may correspond exactly with each other and present nearly the same value, whilst others are wholly different. These substances he calls *hemimorphous*. The most striking example of hemimorphism has been given by Pasteur. He noticed in all the orthorhombic, clinorhombic, and anorthic tartrates a prism of about 100°, surmounted by variable summits.

In certain cases we are compelled to admit isomorphism between substances that do not contain the same number of atoms, as, for example, the alums of ammonia and potassa, and most of the salts furnished by the alkalies and ammonia. The same thing happens, but more rarely, when we see two monatomic atoms play the part and hold the place of one diatomic atom; this is the polymeric isomorphism of Scherer, which seems real within the limits we have just pointed out, but which we can hardly admit as true to the extent given it by its author. According to him, $3\,Al_2\,O_3$ might replace $2\,Si\,O_3$, and even $3\,H\,O$ replace $Mg\,O$ (old equivalents).

The following are the best known examples of isomorphism;—

Cubic Type;—

1. Chloride of potassium	$K\,Cl$.
„ of sodium	$Na\,Cl$
„ of lithium	$Li\,Cl$.
„ of ammonium	$N\,H_4\,Cl$.
„ of cæsium	$Cs\,Cl$.
„ of rubidium	$Rb\,Cl$.
„ of thallium	$Tl\,Cl$.
Bromide of potassium	$K\,Br$.
„ of sodium	$Na\,Br$.
„ of ammonium	$N\,H_4\,Br$.
Iodide of potassium	$K\,I$.
„ of sodium	$Na\,I$.
„ of ammonium	$N\,H_4\,I$.

Cyanide of potassium	KCN.
„ of ammonium	NH_4CN.
Fluoride of potassium	KFl.
„ of sodium	$NaFl$.
2. Sulphuret of lead	PbS.
Seleniuret of lead	$PbSe$.
3. Bisulphide of iron	FeS_2 (pyrites).
„ of manganese	MnS_2 (haüerite).
4. Oxide of magnesium	MgO.
„ of nickel	NiO.
5. The group of the spinelles;—	
Alumino-magnesian oxide	$MgAl_2O_4$ (spinelle).
„ ferrous oxide	$FeAl_2O_4$ (pleonaste).
„ zincic oxide	$ZnAl_2O_4$ (gahnite).
Ferrico-magnesian oxide	$MgFe_2O_4$ (magnoferrite).
„ zincic oxide	$ZnFe_2O_4$ (franklinite).
„ ferrous oxide	$FeFe_2O_4$ (magnetite).
Chromico-ferrous oxide	$FeCr_2O_4$ (chromite).
Oxide of titanium and iron	$TiFe_2O_4$ (iserine).
6. Nitrate of barium	$Ba(NO_3)^2$.
„ of strontium	$Sr(NO_3)^2$.
„ of lead	$Pb(NO_3)^2$.
7. Chlorate of sodium	$NaClO_3$.
Bromate of sodium	$NaBrO_3$.
Iodate of ammonium	NH_4IO_3.
8. Chlorate of nickel	$Ni(ClO_3)^2 + 6H_2O$.
„ of cobalt	$Co(ClO_3)^2 + 6H_2O$.
„ of copper	$Cu(ClO_3)^2 + 6H_2O$.
Bromate of magnesium	$Mg(BrO_3)^2 + 6H_2O$.
„ of zinc	$Zn(BrO_3)^2 + 6H_2O$.
„ of nickel	$Ni(BrO_3)^2 + 6H_2O$.
„ of cobalt	$Co(BrO_3)^2 + 6H_2O$.
9. The group of the garnets, as;— $CaAl_2Si_3O_{12}$ (grossular); $MgAl_2Si_3O_{12}$ (pyrope), &c., &c.	
10. Chloroplatinate of potassium	K_2PtCl_6.
„ of ammonium	$(NH_4)^2PtCl_6$.
Chloro-iridiate of potassium	K_2IrCl_6.
„ of ammonium	$(NH_4)^2IrCl_6$.
Chlorostannate of potassium	K_2SnCl_6.
„ of ammonium	$(NH_4)^2SnCl_6$.
Chloropalladate of potassium	K_2PdCl_6.
„ of ammonium	$(NH_4)PdCl_6$.
11. The group of the alums;—	
Alumino-ammonic	$Al_2(NH_4)^2(SO_4)^4 + 24H_2O$.
Alumino-potassic	$Al_2K_2(SO_4)^4 + 24H_2O$.
Alumino-lithic	$Al_2Li_2(SO_4)^4 + 24H_2O$.
Alumino-thallic	$Al_2Tl_2(SO_4)^4 + 24H_2O$.
Ferrico-potassic	$Fe_2K_2(SO_4)^4 + 24H_2O$.
Ferrico-ammonic	$Fe_2(NH_4)^2(SO_4) + 24H_2O$.
Manganico-potassic	$Mn_2K_2(SO_4)^4 + 24H_2O$.
Manganico-ammonic	$Mn_2(NH_4)^2(SO_4)^4 + 24H_2O$.
Chromico-potassic	$Cr_2K_2(SO_4)^4 + 24H_2O$.
Chromico-ammonic	$Cr_2(NH_4)^2(SO_4)^4 + 24H_2O$.

Quadratic Type;—

1. Stannic oxide	SnO_2.
Titanic oxide	TiO_2.
2. Sulphate of nickel	$NiSO_4 + 7H_2O$.
Seleniate of nickel	$NiSeO_4 + 7H_2O$.
„ of zinc	$ZnSeO_4 + 7H_2O$.
3. Phosphate of potassa	KH_2PO_4.
„ of ammonia	$NH_4H_2PO_4$.
Arseniate of potassa	KH_2AsO_4.
„ of ammonia	$NH_4H_2AsO_4$.
4. Ammoniacal sulphate of silver	$Ag_2SO_4 . 2NH_3$.
„ seleniate of silver	$Ag_2SeO_4 . 2NH_3$.
„ chromate of silver	$Ag_2CrO_4 . 2NH_3$.
5. Sulphate of copper	$CuSO_4 + 6H_2O$.
„ of magnesia	$MgSO_4 + 6H_2O$.
„ of zinc	$ZnSo_4 + 6H_2O$.
„ of nickel	$NiSO_4 + 6H_2O$.
6. Tungstate of lime	$CaWO_4$.
„ of lead	$PbWO_4$.
Molybdate of lead	$PbMoO_4$.

Orthorhombic Type ;—

1.	Arsenious acid	As_2O_3.
	Antimonious acid	Sb_2O_3.
2.	Hydrate of alumina	$Al_2H_2O_4$.
	Ferric hydrate	$Fe_2H_2O_4$.
	Manganic hydrate	$Mn_2H_2O_4$.
3.	Carbonate of lime	$CaCO_3$ (arragonite).
	" of barytes	$BaCO_3$.
	" of strontia	$SrCO_3$.
	" of lead	$PbSO_3$.
4.	Sulphate of lime	$CaSO_4$.
	" of barytes	$BaSO_4$.
	" of strontia	$SrSO_4$.
	" of lead	$PbSO_4$.
5.	Perchlorate of potassa	$KClO_4$.
	" of ammonia	NH_4ClO_4.
	Permanganate of potassa	$KMnO_4$.
	" of ammonia	NH_4MnO_4.
6.	Sulphate of soda	Na_2SO_4.
	" of silver	Ag_2SO_4.
	Seleniate of soda	Na_2SeO_4.
	" of silver	Ag_2SeO_4.
7.	Sulphate of potassa	K_2SO_4.
	" of ammonia	NH_4SO_4.
	" of thallium	Tl_2SO_4.
	Seleniate of potassa	K_2SeO_4.
	Chromate of potassa	K_2CrO_4.
	Manganate of potassa	K_2MnO_4.
8.	Sulphate of magnesia	$MgSO_4 + 7H_2O$.
	" of zinc	$ZnSO_4 + 7H_2O$.
	" of nickel	$NiSO_4 + 7H_2O$.
	" of iron	$FeSO_4 + 7H_2O$.
	" of cobalt	$CoSO_4 + 7H_2O$.
9.	Sulphuret of antimony	Sb_2S_3.
	" of arsenic	As_2S_3.
10.	Nitrate of potassa	KNO_3.
	" of ammonia	NH_4NO_3.
	" of silver	$AgNO_3$.
11.	Phosphate of soda	$NaH_2PO_4 + H_2O$.
	Arseniate of soda	$NaH_2AsO_4 + H_2O$.
12.	Hydrophosphate of copper	$Cu_2(PO_4)OH$.
	Hydroarseniate of copper	$Cu_2(AsO_4)OH$.
	" of zinc	$Zn_2(AsO_4)OH$.
13.	Bitartrate of potassa	$C_4H_5KO_6$.
	" of thallium	$C_4H_5TlO_6$.
14.	Sodico-potassic tartrate	$C_4H_4KNaO_6 + 4H_2O$.
	Sodico-thallous tartrate	$C_4H_4TlNaO_6 + 4H_2O$.

Rhombohedral Type ;—

1.	Arsenic.	
	Antimony.	
	Bismuth.	
2.	Alumina	Al_2O_3 (corundum).
	Ferric oxide	Fe_2O_3.
	Ferrico-titanic oxide	$FeTiO_3$.
	Chromic oxide	Cr_2O_3.
3.	Carbonate of lime	$CaCO_3$ (calcite).
	" of magnesia	$MgCO_3$.
	Dolomite	$Mg\frac{1}{2}Ca\frac{1}{2}CO_3$.
	Carbonate of manganese	$MnCO_3$.
	" of zinc	$ZnCO_3$.
	" of iron	FCO_3.
4.	Sulphuret of cadmium	CdS.
	" of zinc	ZnS.
5.	Nitrate of soda	$NaNO_3$.
	" of potassa	KNO_3.
6.	Hyposulphate of lime	$CaS_2O_6 + 4H_2O$.
	" of strontia	$SrS_2O_6 + 4H_2O$.
	" of lead	$PbS_2O_6 + 4H_2O$.
7.	Chlorphosphate of lime	$Ca_5(PO_4)^3Cl$.
	" of strontia	$Sr_5(PO_4)^3Cl$.
	" of lead	$Pb_5(PO_4)^3Cl$.
8.	Fluozirconate of nickel	$NiZrFl_6 + 6H_2O$.
	Fluosilicate of nickel	$NiSiFl_6 + 6H_2O$.
	Fluostannate of nickel	$NiSnFl_6 + 6H_2O$.
	Fluozirconate of zinc	$ZnZrFl_6 + 6H_2O$.

Clinorhombic Type;—

1. Acid sulphate of potassa	$KHSO_4$.
Acid seleniate of potassa	$KHSeO_4$.
2. Sulphate of lime	$CaSO_4 + 2H_2O$ (gypsum).
Seleniate of lime	$CaSeO_4 + 2H_2O$.
3. Seleniate of magnesia	$MgSeO_4 + 7H_2O$
„ of cobalt	$CoSeO_4 + 7H_2O$.
4. Sulphate of iron	$FeSO_4 + 6H_2O$.
„ of cobalt	$CoSO_4 + 6H_2O$.
„ of manganese	$MnSO_4 + 6H_2O$.
Seleniate of cobalt	$CoSeO_4 + 6H_2O$.
5. Double sulphates	$K_2SO_4 + RSO_4 + 6H_2O$.
Double sulphates	$(NH_4)^2SO_4 + RSO_4 + 6H_2O$.
With R = Ca, Ni, Co, Fe, Mn, Zn, Cu.	
Zinco-thallous sulphate	$Tl_2SO_4 + ZnSO_4 + 6H_2O$.
6. Sulphate of soda	$Na_2SO_4 + 10H_2O$.
Seleniate of soda	$Na_2SeO_4 + 10H_2O$.
Chromate of soda	$Na_2CrO_4 + 10H_2O$.
7. Phosphate of ammonia	$(NH_4)^2HPO_4$.
Arseniate of ammonia	$(NH_4)^2HAsO_4$.
8. Fluostannate of copper	$CuSnFl_6 + 4H_2O$.
Fluosilicate of copper	$CuSiFl_6 + 4H_2O$.
Fluotitanate of copper	$CuTiFl_6 + 4H_2O$.
Fluoxytungstate of copper	$CuWFl_4O_2 + 4H_2O$.
9. Fluoxyniobate of potassa	$K_3HNbOFl_7$.
Fluostannate of potassa	K_3HSnFl_8.

Anorthic type;—

1. Sulphate of copper	$CuSO_4 + 5H_2O$.
„ of manganese	$MnSO_4 + 5H_2O$.
„ of iron	$FeSO_4 + 5H_2O$.
Seleniate of copper	$CuSeO_4 + 5H_2O$.
„ of manganese	$MnSeO_4 + 5H_2O$.
2. Bichromate of potassa	$K_2Cr_2O_7$.
„ of silver	$Ag_2Cr_2O_7$.

JACK. Fr., *Cric à crémaillère*; Ger., *Winde mit gezahnter Stange*; Ital., *Cricco*; Span., *Gato.*

The word *jack* is used in an engineering sense to designate a portable machine, variously constructed, for raising great weights through a small space, as by means of a pedestal or support, Figs. 3855 to 3857, in which works a screw, lever, rack and pinion, or some combination of simple mechanical powers; it is also generally applied to any appendage of a machine, rendering convenient service, as the vibrating levers of a stocking frame.

The *Hydraulic Lifting Jack*, Figs. 4636 to 4639, was introduced by James Tangye. It consists of an inverted hydraulic press A, the ram of which C forms the foot upon which the jack stands, and the pump G and reservoir of water F are fixed on the opposite end of the press-cylinder, and form the head of the jack. The ram C is of wrought

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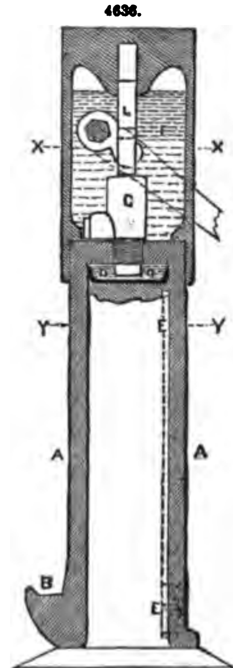

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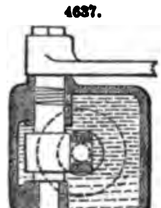

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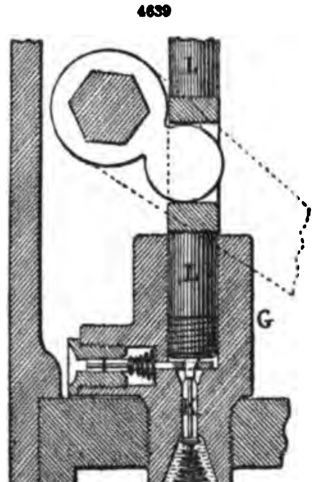

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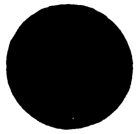

iron, 3½ in. diameter and 12 in. length of stroke, with the foot forged upon it; and the press-cylinder A is formed of a hammered wrought-iron bar, bored out of the solid, leaving ⅝ in. thickness

of metal for the sides of the cylinder. A claw B is forged on one side of the cylinder at the bottom, for the purpose of using the jack to lift from the bottom when required. The head F forming the reservoir of water is of malleable cast iron, fixed upon the top end of the cylinder by being bored out a tight fit and pressed on up to a shoulder.

The jack is lowered by means of a self-acting motion connected with the force-pump lever. The length of stroke of the lever is limited in ordinary working, by a stop-pin fixed on the side of the cistern, which catches the lever at the bottom of its stroke; but by shifting the lever ½ in. outwards upon the squared end of the shaft, it is made to clear this stop-pin, and is pushed down into a lower position. The suction-valve I, Fig. 4639, is forced open by the same movement that presses open the delivery-valve K by means of a small inclined plane upon the prolonged end of the plunger L, which passes through an eye in the stalk of the suction-valve I, and draws back the valve from its seat directly after the delivery-valve K has been pressed open, allowing the water to flow back into the reservoir in the contrary direction to the ordinary working.

The ram of the jack is packed with a cupped leather D, shown black in Fig. 4636, resting in a hollow $\frac{3}{16}$ in. deep turned in the top of the ram. These leathers have been found successful in standing the pressure and wear, the same leathers having been in regular work for several years without requiring renewal. The force-pump plunger L in the lifting jack and also in the shears and punch is packed with a narrow strip of leather $\frac{3}{8}$ in. wide, coiled round spirally in a groove turned near the bottom of the plunger, as in Figs. 4636 and 4639, with the ends of the strip bevelled off to fill up the groove close.

The hydraulic jack in Fig. 4636 is for lifting 30 tons, and different sizes are made for weights from 4 to 60 tons. The head of the jack is prevented from turning round by a sliding block working in a longitudinal groove E in the ram; but by withdrawing the screw that fixes the block the head is allowed to turn freely with the load upon it. The hydraulic jack is convenient for use with heavy weights, from the great power obtained, one man being able to lift readily 30 tons and upwards; and from the lightness of construction, the 30-ton jack weighing about 1½ cwt. At the same time the loss of power from friction is comparatively small; and the small extent of wear to which the working parts are subjected gives great durability and freedom from risk of derangement.

JACK-SCREW. Fr., *Vérin;* Ger., *Schraubenwinde.*

See Jack.

JACKET, STEAM. Fr., *Chemise du cylindre;* Ger., *Dampfmantel;* Ital., *Camicia.*

A jacket is an annular casing enveloping the cylinder of a steam-engine, and is filled with hot steam from the boiler, to prevent the liquefaction of the steam in the cylinder. That liquefaction does not, when it first takes place, directly constitute a waste of heat or of energy, for it is accompanied by a corresponding performance of work. It does, however, afterwards indirectly diminish the efficiency of the engine; for the water which becomes liquid in the cylinder, probably in the form of mist and spray, acts as a distributor of heat and equalizer of temperature, abstracting heat from the hot and dense steam during its admission into the cylinder, and communicating that heat of the cool and rarefied steam which is on the point of being discharged, thus lowering the initial pressure and increasing the final pressure of the steam, but lowering the initial pressure much more than the final pressure is increased, and so producing a less energy which cannot be estimated theoretically. Accordingly, in all cases in which steam is expanded to more than three or four times its initial volume, it has in practice been the custom to envelop the cylinder in a steam-jacket. The liquefaction which would otherwise have taken place in the cylinder, takes place in the jacket instead, where the presence of the liquid water produces no bad effect; and that water is returned to the boiler.

In double-cylinder engines it is usual to have steam-jackets round both cylinders; but in a few examples in which the smaller cylinder is jacketed, the liquefaction is found to be prevented, showing that the steam during its passage from the small into the large cylinder receives sufficient heat either directly from the small cylinder, or indirectly by conduction from the small to the large cylinder, to prevent any appreciable portion of it from condensing. It is desirable that a small quantity of the steam, not appreciable in calculating the efficiency of the engine, should be liquefied, in order to lubricate the packing of the piston. This generally does take place in jacketed engines, and is probably the effect of attraction between the particles of water and the metal.

Spite, however, of the above considerations, many engineers now consider the use of a steam-jacket a doubtful advantage.

See Boiler. Details of Engines, p. 1195.

JACQUARD LOOM. Fr., *Machine jacquarde;* Ger., *Jacquardmaschine;* Ital., *Telaio alla, Jacquard;* Span., *Telar de Jacquard.*

See Loom.

JENNY. Fr., *Machine à filer en fin, Jeannette;* Ger., *Feinspinnmaschine, Jenny;* Ital., *Mulinello da filare;* Span., *Máquina de hilar.*

See Cotton Machinery.

JETTY. Fr., *Jetée de port, Muelle;* Ger., *Kafendamm;* Ital., *Molo;* Span., *Muelle.*

An erection projecting into the sea, of the nature of a pier, with open spaces for the sea to play in, mostly constructed of timber. See Piers.

JOGGLE. Fr., *Entaille à crémaillère;* Ger., *Zahneinschnitt.*

A joggle is a joint between two bodies, so constructed by means of jogs or notches as to prevent their sliding past each other. See Joints.

JOINTS. Fr., *Joints;* Ger., *Stoss, Fuge;* Ital., *Guintura;* Span., *Juntas.*

The places or parts in which any two pieces of material meet are called joints, as the joints between two pieces of timber. Figs. 4640 to 4677 show various arrangements of joints used in joinery for panels, interior and exterior angles, and similar purposes.

Fig. 4640 is of a joint formed by planing the edges of a board perfectly true, and inserting

wooden or iron pins at intervals into the edge of both boards. The pin is called a dowel, and the joint is said to be doweled.

Fig. 4641, a joint formed by grooving and tonguing, or, as it is otherwise termed, grooving and feathering, ploughing and tonguing or feathering.

These two last joints are commonly used for floors. The first is used without the dowels in ordinary folded floors. The shrinking of the boards in this case causes the joint to open, and the air and dust to pass through. The grooved and tongued joint is used in the better kind of floors. The tongue or feather prevents the passage of air or dust.

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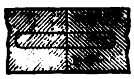
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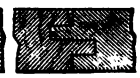
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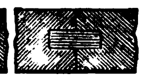

Fig. 4642, a double-tongued or feathered joint. Fig. 4643, a combination of a rebate with a groove and tongue. It affords in flooring a better means of nailing. In Fig. 4644 the groove and tongue are angular.

Fig. 4645, a kind of grooving and tonguing resorted to when the timber is thick, or when the tongue requires to be stronger than it would be if formed in the wood itself. In this mode of jointing corresponding grooves are formed in the edges of the boards, and the tongue or feather is formed of a slip of harder or stronger wood, called a slip-feather.

Figs. 4646 to 4648 are slip-feather joints. The feather in Fig. 4648 is wrought iron.

Fig. 4649 shows dovetail grooves, with a slip-feather of corresponding form, which must be inserted endways.

Fig. 4650 is a simple rebated joint. One-half of the thickness of each board is cut away to the same extent, and when the edges are lapped the surfaces lie in the same plane.

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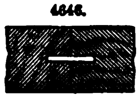
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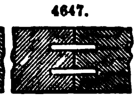
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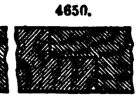
4651


Fig. 4651, a complex mode of grooving and tonguing. The joint is in this case put together by sliding the one edge with its grooves and tongues endways into the corresponding projections and recesses of the other. The boards, when thus jointed together, cannot be drawn asunder laterally or to their surface without rending; but in the event of shrinking there is great risk of the wood being rent.

Where a great surface has to be covered with boarding not framed, the deals are cut into narrow widths, and jointed at their edges by some of the joints just described. Fig. 4641 shows the simple groove-and-tongue joint, which shrinkage of the wood will cause to open and disfigure the work. To prevent this disfigurement, a small moulding, termed a bead, is sometimes run on the edge of each board.

The joint thus forms one of the quirks of the bead, and prevents any slight opening being observed. This is termed a grooved tongued and beaded joint. So also in the case of the rebated joint, a bead is run on the edges of the board, and this is termed a rebated and beaded joint.

In joining angles formed by the meeting of two boards various joints are used, among which are;—

Fig. 4652, the mitre-joint, used in joining two boards at right angles to each other. Each edge is planed to an angle of 45°.

Fig. 4653, a mitre-joint keyed by a slip-feather.

Fig. 4654, a mitre-joint when the boards are of different thickness. The mitre on the thicker piece is only formed to the same extent as that on the edge of the thinner piece; hence there is a combination of the mitre and simple butt joint.

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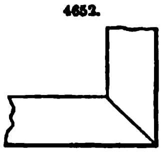
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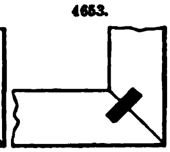
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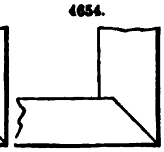
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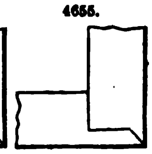
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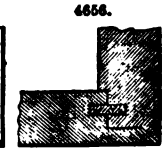


Fig. 4655 shows a different mode of joining two boards of either the same or different thicknesses. One of the boards is rebated, and only a small portion at the angle of each board is mitred. This joint may be nailed both ways.

In Fig. 4656 both boards are rebated, and a slip-feather is inserted as a key. This also may be nailed through from both faces.

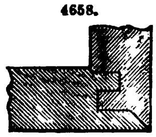
Figs. 4657, 4658, are combinations of grooving and tonguing with the last described modes. These can be fitted with accuracy and joined with certainty.

Fig. 4659 is a joint formed by the combination of mitring with double grooving and tonguing, Fig. 4651. The boards must in this case be slipped together endways, and cannot be separated by a force applied at right angles to the planes of their surfaces.

In all these mitre-joints the faces of the boards meet at the angle, and the slight opening which

might be caused by shrinkage would be scarcely observable. In the butt-joints which follow, the face of the one board abuts against the face of the other, the edge of which is consequently in

4657.

4658.

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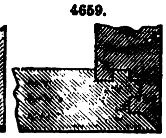
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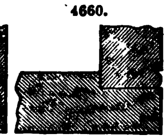
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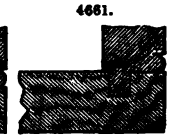

the plane of the surface of the first board, and the shrinkage of which would cause an opening at the joint. To make this opening less apparent, is the object of forming the bead-moulding, Figs. 4660 to 4664.

In Fig. 4660 the thicker board is rebated from the face, and a small bead formed on the external angle of the abutting board.

Fig. 4661, a groove is formed in the inner face of the one board and a tongue on the edge of the other.

Fig. 4662, the boards are grooved and tongued as in the last figure. A cavetto is run on the external angle of the abutting board, and the bead and a cavetto on the internal angle of the other board.

Fig. 4663, a quirked bead run on the edge of one board, and the edge of the abutting board forms the double quirk.

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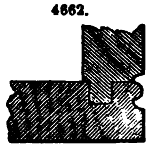
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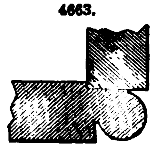
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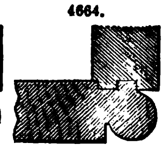
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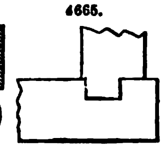
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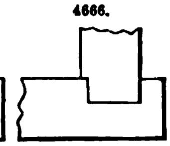
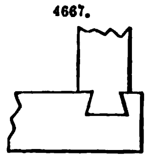


Fig. 4664, a double quirk bead is formed at the external angle, and the boards are grooved and tongued. The external bead is attended with this advantage, that it is not so liable to injure as the sharp arris.

In Figs. 4665, 4666, the joints used in putting together cisterns are shown. Figs. 4667, 4668, are joints for the same purpose. They are of the dovetail form, and require to be slipped together endways.

4667.

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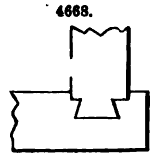
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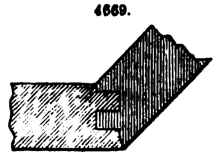
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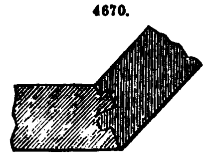

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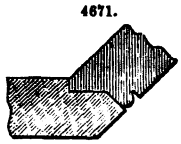
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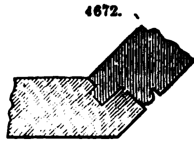
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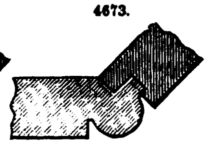
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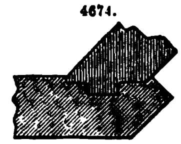
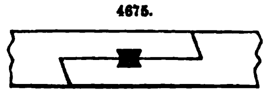


Figs. 4669 to 4674 show the same kind of joints as have been described, applied to the framing together of boards meeting in an obtuse angle.

Figs. 4675, 4676, show methods of joining boards together laterally by keys in the manner of scarfing; and Fig. 4677, another method of securing two pieces, such as those of a circular window fram-head by keys.

4675.

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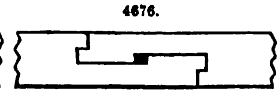
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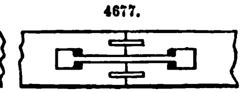


Dovetail Joint.—This joint has three varieties;—the common dovetail, where the dovetails are seen on each side of the angle alternately; the lapped dovetail, in which the dovetails are seen only on one side of the angle; and the lapped and mitred dovetail, in which the joint appears externally as a common mitre-joint. The lapped and mitred joint is useful in salient angles, in finished work, but it is not so strong as the common dovetail, and therefore in all re-entrant angles the latter should be used.

The three varieties of dovetail-joint above enumerated are illustrated in Figs. 4678 to 4691.

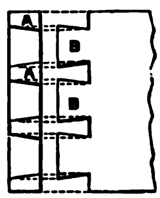
Fig. 4678 is an elevation; Fig. 4679 a view in perspective; and Fig. 4680 a plan of the

common dovetail-joint. In all the figures, the pins or dovetails of the one side are marked A, and those of the other side are marked B.

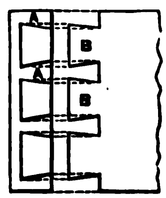
Lap-joint is represented in plan, elevation, and perspective projections, Figs. 4681 to 4683.

Figs. 4684 to 4686 are a plan, elevation, and perspective projection of the mitred dovetail-joint. The dovetails of the adjoining sides are marked respectively B and C in all the figures.

4678.



4681.



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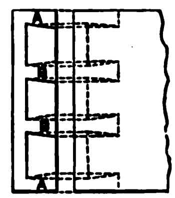
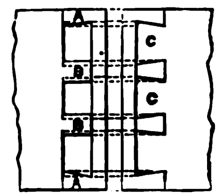
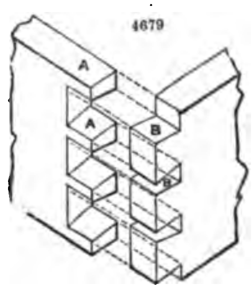


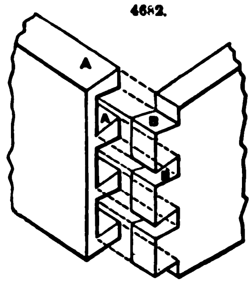
4685.



4679



4682.



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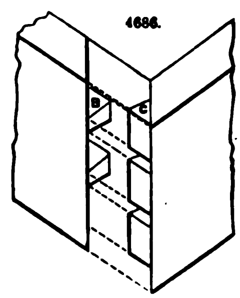

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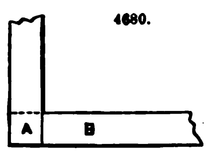
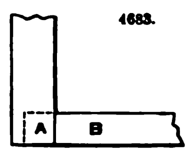


4683.



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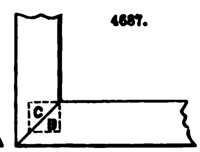
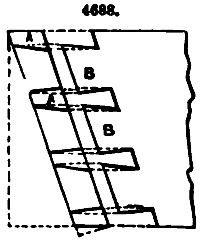
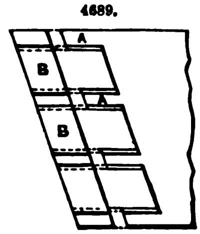


Figs. 4688 to 4691 show the modes of dovetailing an angle, when the sides are inclined to the horizon, as in a hopper. The pins of the one side are marked A, and those of the other side B.

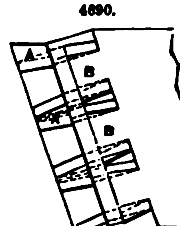
4688.



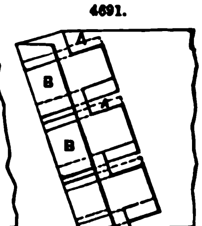
4689.



4690.



4691.



The meeting of two pieces of wood is called in carpentry the joint, which is circumscribed by the lines which mark the intersection of the faces of one piece with the other. The end of a piece of wood properly cut to be adjusted in contact with another piece is called its abutment. That a joint may be at the same time simple and easy of execution, it is necessary that the bearing faces should be planed of the same size and shape in relation to the planes of the axes. This can only take place when two faces of each piece are perpendicular to the same plane, and the other two faces parallel. This consideration will show that the two pieces of wood must necessarily be square.

When two pieces of wood are joined by the simple contact of the end of one piece with its bed on the other, they are said to abut or are joined by a plain-joint. This mode of joining does not prevent the one piece sliding on the other, unless it is fastened with nails or bolts.

The putting together of two pieces of wood may be effected in various ways—say that they meet and form an angle; then this mode has three cases;—

1. The end of one piece may bear upon a point in the length of the other. This case is the most frequent, and gives rise to the mortise-and-tenon joint, the joggle-joint, and to all those which are modifications of these two.

2. The two pieces can be joined mutually by their extremities under any angle whatever. This forms the angle-joint.

3. They may cross each other; and this result is the notch-joint.

Two pieces of wood may be joined in a right line by lapping and indenting the meeting ends on each other. This is called scarfing.

Two pieces of wood may be joined longitudinally end to end, the joint being secured by covering it on opposite sides by pieces of wood bolted to both beams. This process is termed fishing.

It is requisite to consider the joint as formed by two pieces only, because joints formed by more than two pieces can always be resolved into this.

The mortise-and-tenon joint is the principal of the greatest number of the other joints. It is necessary therefore to describe it first at length.

In the simplest case of tenon-and-mortise joint the two pieces of wood meet at right angles, Fig. 2069. The tenon is formed at the extremity of the upper piece in the direction of its fibres and parallel to its axis by two notches, which take from each side a parallelopipedon. The planes of the sides of the tenon are always parallel to the face of the upper piece and the other planes of the notch at right angles to it. The mortise is hollowed in the face of the lower piece, and is of exactly the same size and form as the tenon which therefore fills it. The two sides of the mortise which correspond to the breadth of the tenon should be parallel to the direction of the fibres of the wood. The sides of the mortise are called its cheeks; and the square parts of the timber from which the tenon projects, and which rest on the cheeks of the mortise, are called the shoulders of the tenon; and its springing from these is called its root. As the cheeks of the mortise and the tenon are exposed to the same amount of strain in a system of framing, it follows that each should be equal to one-third of the thickness of the timbers in which they are made. The length of the tenon should be equal to the depth of the mortise, so that its end should press home on the bottom of the mortise when its shoulders bear upon the cheeks; but as perfection in execution is not attainable, the tenon, in practice, is always made a very little shorter than the depth of the mortise, that its shoulders may come close.

When the mortise-and-tenon joint is cut, adjusted, and put together, the pieces are united by a key or treenail. The key is generally round, with a square head, and in diameter is always equal to a fourth part of the tenon. It is generally inserted at the distance of one-third of the length of the tenon from the shoulder; but a key should never be depended upon as a means of securing the joint, for the immobility of a system of framing should result from the balancing of the forces and the precision of the execution. A frame fixed definitely in its place should be stable and solid without the aid of keys, which are to be regarded as mere auxiliaries, useful during its construction.

If the endeavour is made to apply the same manner of forming the mortise and tenon when the timbers are not at right angles, but oblique, several disadvantages arise.

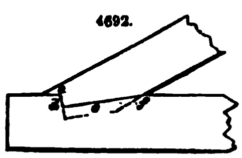
If there were no other inconveniences the impossibility of inserting the tenon in the mortise when the pieces form a portion of a system would preclude its adoption, as it would require to be thrust into the mortise in the direction of the arrow; but added to this there is the difficulty of working the mortise, and the tendency of the thrust of the tenon to rend the lower piece.

All these inconveniences are remedied in a very simple manner by truncating the tenon on the line $a f$, as shown in Fig. 4692, by a plane perpendicular to the axis of the mortise-piece. The execution is thus rendered easy and exact, the evil from the thrust of the tenon obviated, and the pieces can be put together by dropping the tenon-piece vertically into the mortise.

This is the simplest form of the mortise-and-tenon joint for oblique thrusts; but the only resistance offered to the sliding of the tenon-piece along the mortise-piece is offered by the strength of the tenon, which is quite insufficient in large carpentry works, and it is therefore necessary to modify the form so as to bring new bearing surfaces into action.

Fig. 4692 shows the joint formed by the meeting of a principal rafter and tie-beam, c being the tenon. The cheeks of th mortise are cut down to the line $d f$, so that an abutment $e d$ is formed of

4692.



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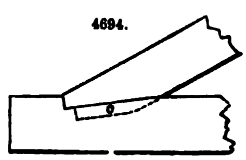

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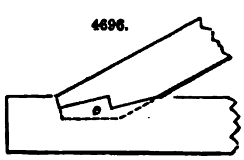

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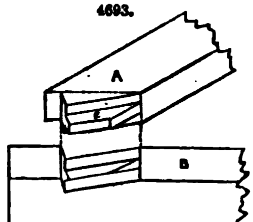

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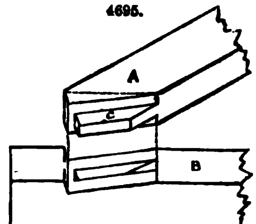

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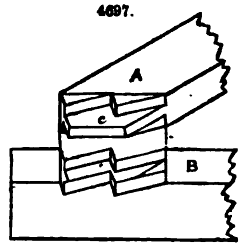


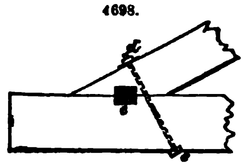
the whole width of the cheeks, in addition to that of the tenon; and the notch so formed is called a joggle. Fig. 4693 shows the parts detached and in perspective. It will be seen that a much larger bearing surface is thus obtained.

Fig. 4693 is a geometrical elevation of a joint, differing from the last by having the anterior part of the rafter truncated, and the shoulder of the tenon returned in front. It is represented in perspective in Fig. 4694.

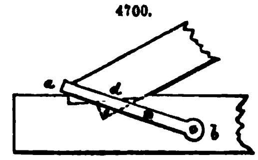
Figs. 4696, 4697, show the geometrical elevation and perspective representation of an oblique joint, in which a double abutment, as *d e*, Figs. 4692, 4693, should be perpendicular, *d f*; and in execution the joint should be a little free at *f*, in order that it may not be thrown out at *d* by the settling of the framing. The double abutment is a questionable advantage; it increases the difficulty of execution, and of course the evils resulting from bad fitting. It is only allowable where the angle of meeting of the timbers is very acute, and the bearing surfaces are consequently very long.

Figs. 4698, 4699, show a means of obtaining resistance to sliding by inserting the piece *c* in notches formed in the rafter and the tie-beam; *d e* shows the mode of securing the joint by a bolt.

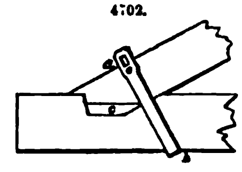
4698.



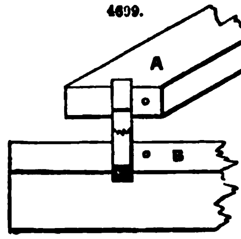
4700.



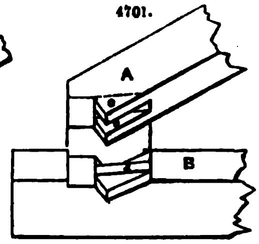
4702.



4699.



4701.



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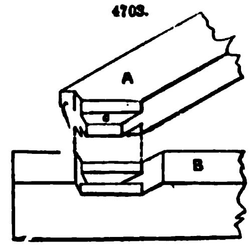


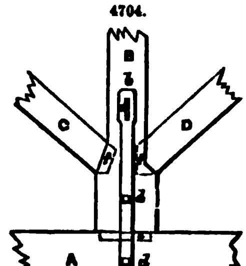
Figs. 4700, 4701, are of a very good form of joint, in which the place of the mortise is supplied by a groove *c* in the rafter, and the place of the tenon by a tongue *d* in the tie-beam. As the parts can be all seen they can be more accurately fitted, which is an advantage in heavy work. In Fig. 4700 the mode of securing the joint by a strap *a b* and bolts is shown.

Figs. 4702, 4703, are another mortise-joint, secured by a strap *a b* and cotter or wedge *a*.

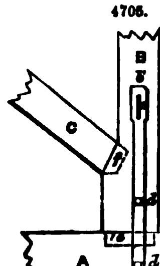
Fig. 4704 shows the several joints which occur in framing the king-post into the tie-beam and the struts into the king-post. A is the tie-beam; B, the king-post; and *c* and D, struts. The joint at the bottom of the king-post has merely a short tenon *e* let into a mortise in the tie-beam. The abutment of the strut D is made square to the back of the strut, as far as width of the king-post admits; and a short tenon *f* is inserted into a mortise in the king-post. The abutment of the joint of *c* is formed as nearly square to the strut as possible.

The term king-post gives quite an erroneous notion of its function, which are those of a suspension-tie. Hence the necessity for the long strap *b a*, bolted at *d d*, secured by wedges at *c*, in the manner more distinctly shown by Fig. 4706.

4704.



4705.



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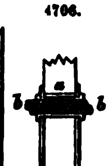

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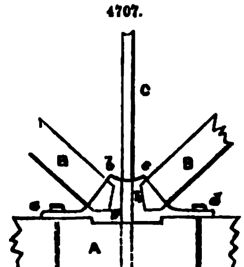
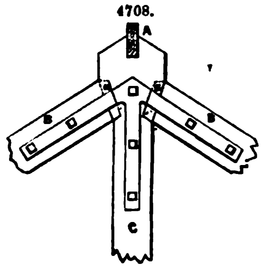


Fig. 4705 shows the queen-post. A is the tie-beam; B the post, tenoned at *e*; *c* the strut; and D the straining-piece; the strap, *b a*; and bolt, *d d*.

Fig. 4707. In this figure a superior construction is shown, in which a king-bolt of iron, C D, is substituted for the king-post. On the tie-beam *a* is bolted, by the bolts *a e d f*, the cast-iron plate and sockets *a b c d*, the inner parts of which, *h g*, *h g*, form solid abutments to the end of the struts B B. The king-bolt passes through a hole in the middle of the cast-iron socket-plate, and is secured below by the nut D. A bottom plate, *e f*, prevents the crushing of the fibres by the bolts.

Figs. 4708 to 4714 show various methods of framing the head of the rafters and king-posts by the aid of straps and bolts. Fig. 4715, the head of the rafters halved and bolted at their junction, and a plate laid over the apex to sustain the bolts which are substituted for the king-post. One bolt necessarily has a link formed in it for the other to pass through.

4708.



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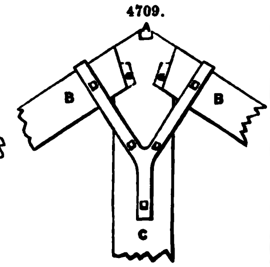
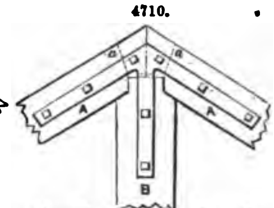
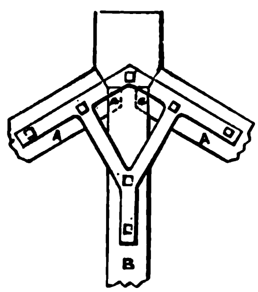


4710.



4711.

4712.



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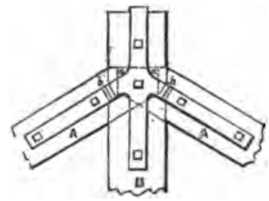

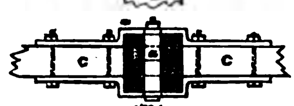

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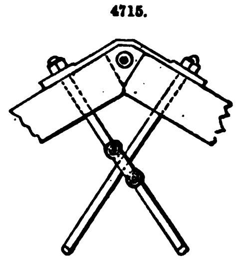
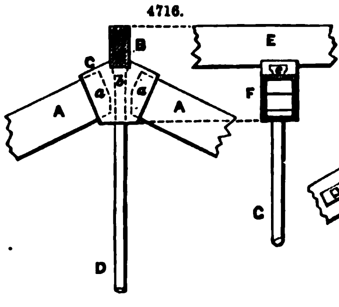


Fig. 4716 shows at D what may be considered the upper part of the same king-bolt, Fig. 4707, with the mode of connecting the rafters. A cast-iron socket-piece *c* receives the tenons *a a* of the rafters A A, and has a hole through it for the bolt, the head of which, *b*, is countersunk. B is the ridge-piece set in a shallow groove in the iron socket-piece. An elevation of the side is given, in which G is the bolt, F the socket-piece, and E the ridge-piece.

4716.



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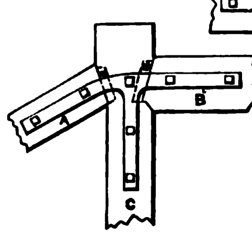

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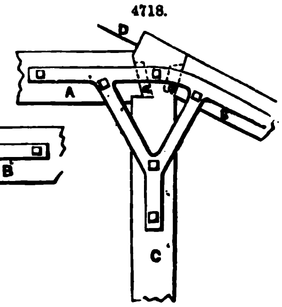

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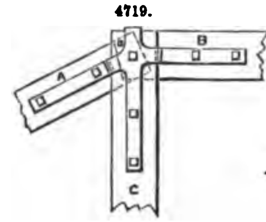

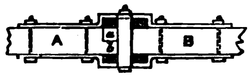

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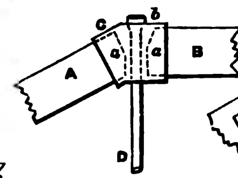

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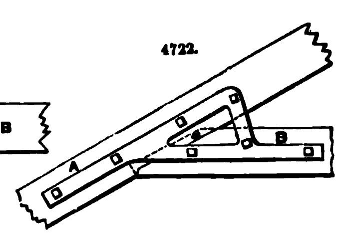
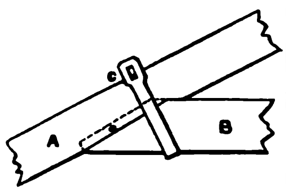


Figs. 4717 to 4721 illustrate the mode of framing together the principal rafter, queen-post, and straining-piece. In the first three examples the joints are secured by straps and bolts, and in the

last example the queen-bolt D passes through a cast-iron socket-piece c which receives the ends of the straining-piece and rafter, as those of the two rafters are received in Fig. 4716.

Figs. 4722, 4723, are modes of securing the junction of the collar-beam and rafters by straps; and Figs. 4724, 4725, modes of securing the junction of the strut and the rafter by straps.

4723.



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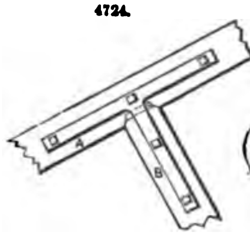

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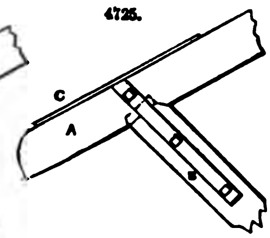
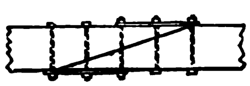


Lengthening Beams.—In large works in carpentry it is often necessary to join timbers in the direction of their length, in order to procure scantlings of sufficient longitudinal dimensions. When it is necessary to maintain the same depth and width in the lengthened beam, the mode of joining called scarfing is employed. Scarfing is performed in a variety of ways, dependent upon whether lengthened beam is to be subjected to a longitudinal or transverse strain. This method of joining is illustrated in Figs. 4726 to 4741.

In Fig. 4726 a part of the thickness is cut obliquely from the end of each piece, and being lapped over each other the joint is secured by bolts. In this case thé joint depends entirely on the bolts. Iron plates are interposed between the nuts and the timber, to prevent the screwing up of the nuts injuring the beam.

4726.



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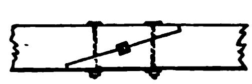

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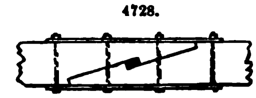

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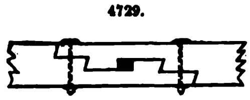

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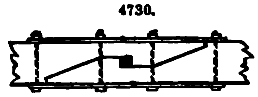

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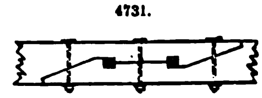

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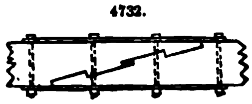

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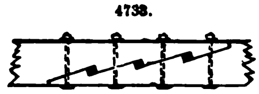

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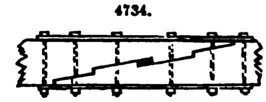

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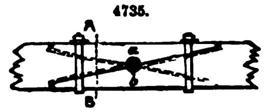

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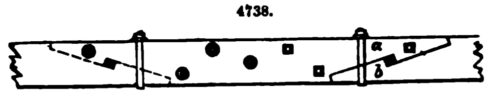

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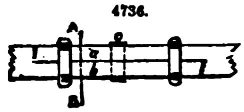
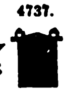


4737.



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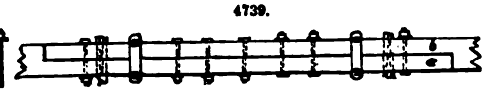
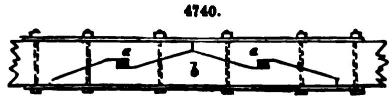
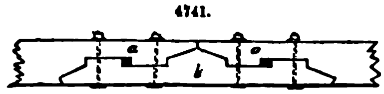


4740.



4741.



In Fig. 4727 a key is added in the middle of the joint, notched equally into both beams. In Fig. 4728 the joint is improved by its surface being indented on each joint and the key driven between. In this example continuous plates of iron are placed to prevent injury from the bolts. Figs. 4729 to 4734 are all variations of the last figure. In Fig. 4735 the beams are halved together vertically, as in Figs. 4736, 4737. They are keyed at the centre and secured by iron straps. In Figs. 4738, 4739, the joint is made much larger and halved; the end of each beam is scarfed and keyed, as in Fig. 4728; and the joint is secured by two straps and seven bolts. Fig. 4738 is the side, and Fig. 4739 the top of the beam.

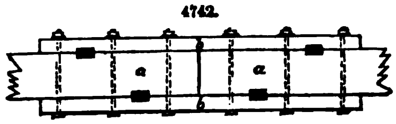
Figs. 4740, 4741, are examples of scarfs formed by the interposition of a third piece b.

When the beam does not require to be of the same dimensions throughout, it is sometimes

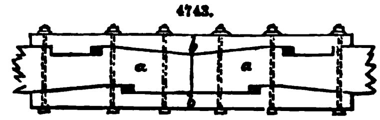
lengthenen by the process termed fishing. The ends of the beams, *a a*, Fig. 4742, are abutted together, and a piece of timber, *b b*, is placed on each side, and secured by bolts and keys.

Fig. 4743 is an example of a fished beam, in which the fishing-pieces *b b* and timbers *a a* are tabled, and indented and keyed together.

4742.

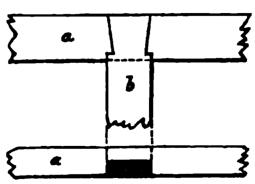


4743.

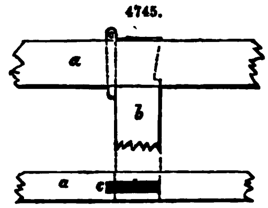


Dovetailing and Halving.—Fig. 4744 shows two pieces of timber joined together at right angles by a dovetailed notch. As to dovetails in general, it is necessary to remark that they should never be depended upon in carpentry for joints exposed to a strain, as a very small degree of shrinkage will allow the joint to draw considerably.

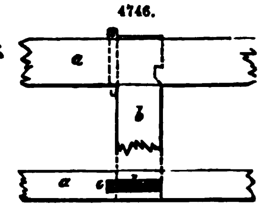
4744.



4745.



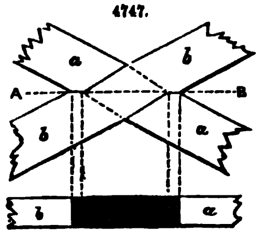
4746.



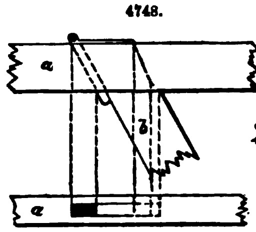
Figs. 4745, 4746, show modes of mortising wherein the tenon has one side dovetailed or notched, and the corresponding side of the mortise also dovetailed or notched. The mortise is made of sufficient width to admit the tenon, and the dovetailed or notched faces are brought in contact by driving home a wedge *c*. Of these, Fig. 4746 is the best.

Fig. 4747 shows the halving of the timbers crossing each other. Fig. 4748 a joint similar to those in Figs. 4745, 4746, but where the one timber *b* is oblique to the other *a*.

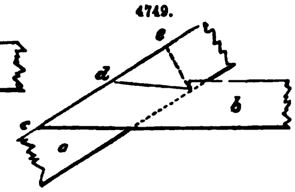
4747.

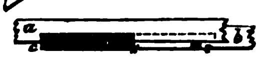


4748.



4749.





4750.

Figs. 4749, 4750, show the mode of notching a collar-beam tie into the side of a rafter by a dovetailed joint. The general remark as to dovetailed joints applies with especial force to this example.

Joints in Metal.—Figs. 4751 to 4774 indicate the methods of uniting the edges of metals after they have been cut and bent to meet in angles, curves, or plane surfaces.

Figs. 4751, 4752, are for the thinnest metals, which require a drop of soft solder on one or other side. Sheet-lead and tin are thus joined, and both are usually soldered from within.

Figs. 4753, 4754, are the mitre and butt joints used for thicker metals with hard solders. Sometimes Fig. 4754 is dovetailed together, the edges being filled to correspond coarsely; they are also partly riveted before being soldered from within. These joints are weak when united with soft solder.

4751. 4752. 753. 4754. 4755. 4756.

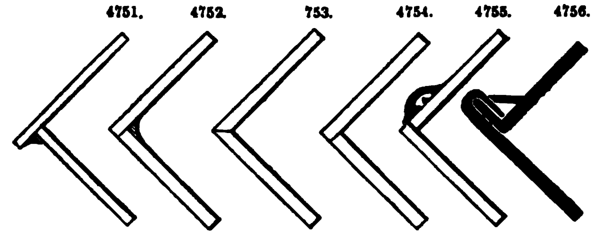


Fig. 4755, a lap-joint; the metal is creased over the hatchet-stake. Tin plate requires an external layer of solder; spelter solder runs the crevice, and need not project.

Fig. 4756 is folded by means of the hatchet-stake; the two are then hammered together, but require a touch of solder to prevent them from sliding asunder.

Fig. 4757, the folded angle-joint, used for cashboxes, and other strong works in which solder

would be inadmissible. It is common in tin and copper works, but less so in iron and zinc, which do not bend so readily.

Fig. 4758, a riveted joint, which is commonly used in strong iron-plate and copper works, as in boilers. Generally a rivet is inserted at each end, then the other holes are punched through the two thicknesses with a punch, on a block of lead. The head of the rivet is put within, the metal is flattened around it by placing the small hole of a riveting set, over the pin of the rivet, and giving a blow; the rivet is then clinched, and it is finished to a circular form by the concave hollow in another riveting set. When the works cannot be laid upon an anvil or stake, a heavy hammer is held against the head of the rivet to receive the blow; in larger works machine tools are used for riveting.

Figs. 4759, 4760, the plates *a a* are punched with long mortises, then *b b* are formed into tenons, which are inserted and riveted; but in Fig. 4760 the tenons have transverse keys tc enable the parts to be separated.

4757. 4758. 4759. 4760. 4761. 4762.

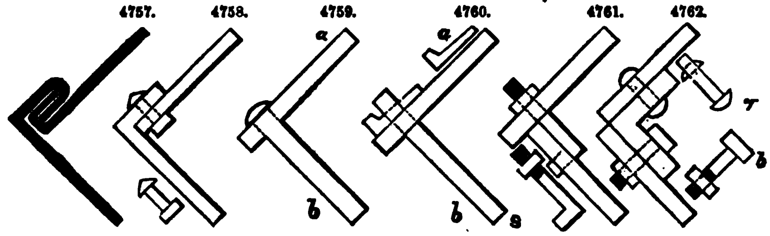


Fig. 4761, the one plate makes a butt-joint with the other, and is fixed by L-formed rivets or screw-bolts *s*; the short ends are generally riveted to the one plate, even when screwed nuts are used. This joint is very common in stovework.

Fig. 4762 is the mode universally adopted for very strong vessels, as for steam-boilers, in which the detached wrought-iron plates are connected by angle-iron. The rivet-holes are punched or drilled. The rivet *r* is made red hot, handed to the workman within the boiler, who drives it in the hole; he then holds a heavy hammer against its head, whilst two operators clench it up from without; between the hammering and the contracting of the metal in cooling the edges are brought together into intimate and powerful contact. Bolts and nuts, *b*, may be used to allow the removal of any part, as the man-hole of the boiler.

For the curved parts of the boilers the angle-iron is bent into corresponding sweeps, and for the corners of square boilers the angle-iron is welded together to form the three tails for the respective angles or edges which constitute the solid corner.

When several plates are required to be joined together to extend their dimensions, or the edges of one plate are united as in forming a tube, the joints are arranged as in Figs. 4763 to 4773, similarly to those for angles, but from which they differ in several respects.

Fig. 4763 is the lap-joint, employed with solder for tin plates, sheet lead, and for tubes bent up in these materials.

Fig. 4764, the butt-joint, used for plates and small tubes of the various metals. United with the hard solders they are moderately strong, but with tin solder the junctions are very weak from the limited measures of the surfaces.

Fig. 4765 is the cramp-joint. The edges are thinned with the hammer, the one is left plain, the other is notched obliquely with shears from $\frac{1}{8}$ to $\frac{1}{4}$ of an inch deep; each alternate cramp is bent up, the others down, for the insertion of the plain edge; they are next hammered together and brazed, after which they may be made nearly flat by the hammer, and quite so by the file. The cramp-joint is used for thin works requiring strength, and, amongst others, for the parts of musical instruments. Sometimes Fig. 4763 is feather-edged: this improves it, but it is still inferior to the cramp-joint in strength.

4765. 4766. 4768.

4763.

4764. 4767. 4769.

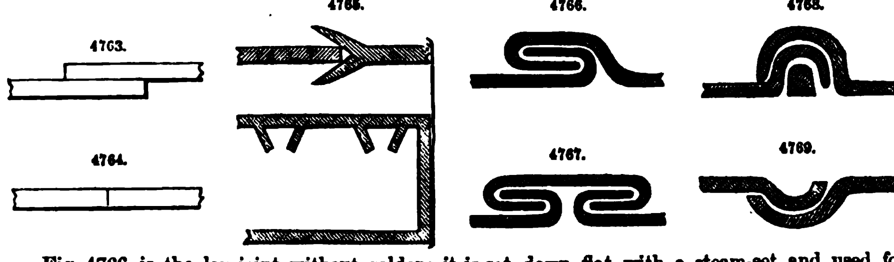


Fig. 4766 is the lap-joint without solder; it is set down flat with a steam-set, and used for smoke-pipes and other arrangements not required to be steam or water tight.

Fig. 4767 is used for zinc works; it saves the double bend of Fig. 4766.

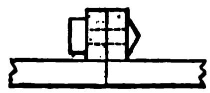
Fig. 4768, the roll-joint employed for lead roofs. The metal is folded over a wooden rib, and requires no solder; the water will not pass through this joint until it exceeds the elevation of the wood. The roll-joint is less bent when used for zinc, as that material is rather brittle; the laps merely extend up the straight sides of the wooden roll, and their edges are covered by a half-round strip of zinc nailed to the wood.

Fig. 4769, a hollow crease used for vessels and chambers for making sulphuric acid; the metal

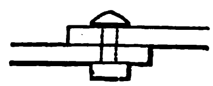
is scraped perfectly clean, filled with lead heated nearly to redness, and the whole are united by burning, with an iron heated also to redness. This method is, however, nearly superseded by the mode of autógenous soldering.

Figs 4770, 4771, are commonly employed either with rivets or screw-bolts; the latter joint is common in boilers, both of copper and iron, and also in tubes. Copper works are frequently tinned all over the rivets and joints, to stop any minute fissures. Fig. 4770 is the flange-joint for pipes.

4770.



4771.



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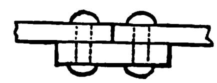

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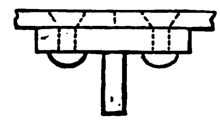
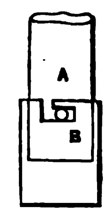


Fig. 4772, with rivets, is a common mode of uniting plates of marine boilers, and other works required to be flush externally.

Fig. 4773, a mode of constructing the largest iron steam-ships. The ribs of the vessels are made of T-iron, varying from about 4 to 8 in. wide, which is bent to the curve by the employment of very large surface-plates cast full of holes, upon which the wood model of the rib is laid down, and a chalk mark is made around its edge. Dogs or pins are wedged at short intervals in all those holes which intersect the curve; the rib, heated to redness in a reverberatory furnace, is wedged fast at one end, and bent round the pins by sets and sledge-hammers, and as it grows or yields to the curve, every part is secured by wedges until the whole is completed.

Fig. 4774 is a bayonet-joint. On turning the part A it is released from the L-shaped slot in the socket B, when it can be withdrawn.

4774.



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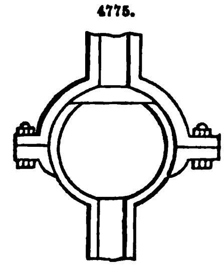

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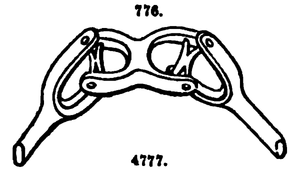

4777.

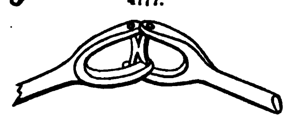

Fig. 4775, a ball-and-socket joint arranged for tubing. Figs. 4776, 4777, two kinds of universal joints.

See CONSTRUCTION. HAND-TOOLS. MACHINE TOOLS.

JOINTS, RIVETED. FR., *Joints rivés*; GER., *Vernieteter Stoss*; ITAL., *Guintura ribadita*; SPAN., *Juntas con roblones.*

See CORROSION. IRON SHIPBUILDING. JOINTS. RIVETING.

JOISTS. FR., *Poutrelle*; GER., *Kleine Balken*; ITAL., *Trave*; SPAN., *Viguetas.*

Joists are small pieces of timber resting on the wall or the girders in a house, and to which the boards of a floor or the laths of a ceiling are nailed. See CONSTRUCTION.

JOURNAL. FR., *Tourillon*; GER., *Drehzapfen.*

The short cylindrical portion of a shaft or other revolving piece, which turns in some other piece, or in a support called a *journal*-box; a bearing. See AXLE.

JOURNAL-BOX. FR., *Boite de tourillon*; GER., *Zapfenlager*; ITAL., *Bronzina*; SPAN., *Caja donde gira un eje.*

The journal-box is that part of a machine in which the journal of a shaft, axle, or pin bears and moves, strictly a box in two or more parts, so that it can be opened and adjusted; called also simply box. When there is a separate piece enclosed by the box and bearing on the journal, this piece is termed a brass. See JOURNAL.

KEELS AND COAL SHIPPING.

In the early days of English coal shipping, the coals were brought down to the edge of the river in wagons, and there put into keels, which were broad, flat-bottomed barges, each containing a keel of coals, or 8 Newcastle chaldrons = 21 tons 4 cwt.

On the river Tyne there were many collieries having communication by railways to shipping places, where vessels could load, as in the case of the Walls-End Colliery. The mode of shipment was by spouts, in their general principles similar to those adopted by T. E. Harrison at the Tyne Docks, but without, for a long time, any arrangement for meeting the difference in the level of the tide and in the size of the vessel. When keels were used, the coals were brought down in them to where the vessel lay in the river, and they were then cast into the vessel through the porthole by the keelmen.

The first innovation on the spout system took place in the year 1812, when a coal-drop was erected on the river Tyne by Benjamin Thompson, and further improved by him in 1813. The principle of this mode of shipping coals was the invention of W. Chapman, but the credit of bringing the system into practical operation is due to Thompson. The drops, Figs. 4778, 4779, as erected by

him in 1813, have been generally followed, with various modifications. The principle of all these drops is, that the loaded wagon in its descent raises a counterbalance weight; and when the coals

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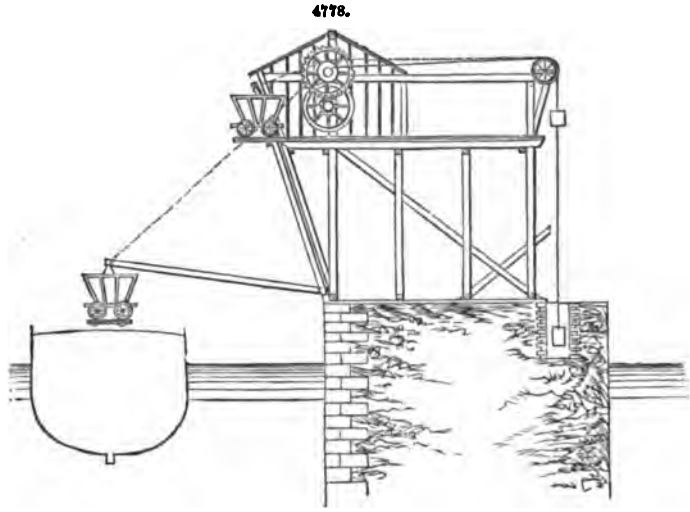
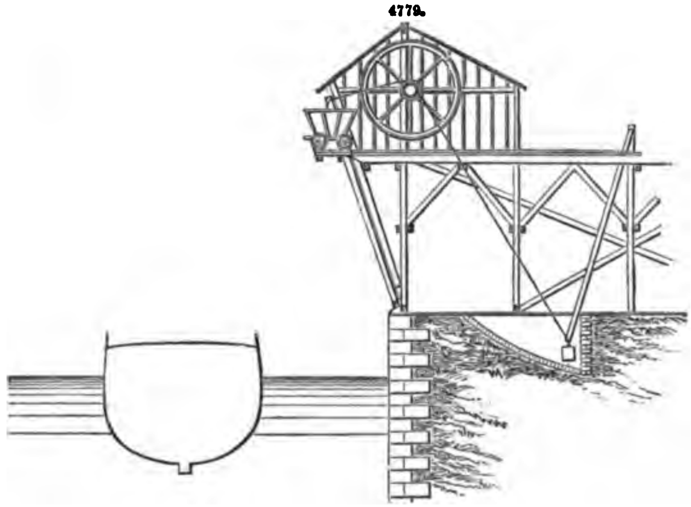


4779.



are let out of the wagon, the counterbalance weight brings the wagon back to its previous position, the whole being under the control of powerful brakes.

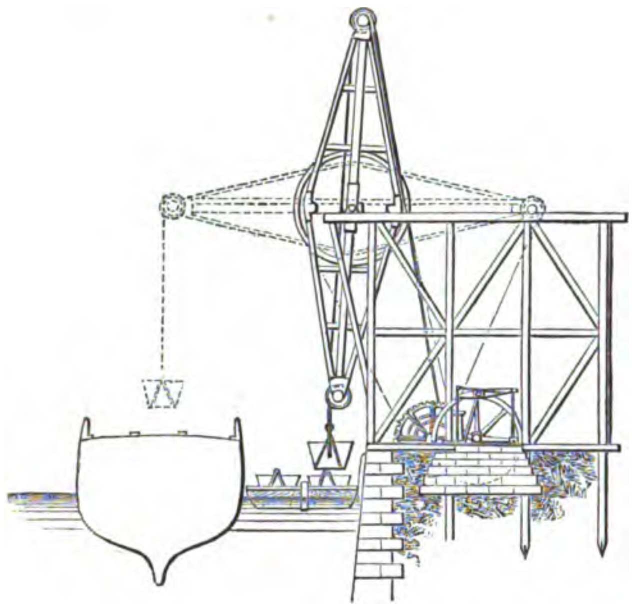
The first change on the keel system took place on the river Wear in the year 1817, when, in order to avoid the breakage to which the coals were subject by trans-shipment, first to the keel and then from the keel to the ship, a system of tubs, Figs. 4780, 4781, fitted into the keels, was invented by W. Bell. The chaldron wagons were lowered immediately over the keel, and then dropped into the tubs; the tubs were then conveyed in the keels, and transferred by the machinery to the vessel.

Figs. 4786, 4787, are a combination of both Bell and Thompson's plans, the system of tubs and the counterweight being both retained. Another system, Fig. 4782, which is still at work, was introduced in Sunderland about the same time.

In the year 1822, a private line of railway was made to Sunderland for the collieries, since the property of the Earl of Durham. The coals were there loaded direct into the ships by drops, Fig. 4783. These were the first drops erected on the river Wear. Figs. 4784, 4785, are a modification of this plan, which is very generally used.

In determining the system to be adopted in the Tyne Docks, the question lay between drops, by which the wagon would be lowered directly on to the deck of the vessel, and a system of spouts, with more perfect appliances for preventing the breakage of the coals. After mature deliberation, watching carefully the best-constructed spouts, and considering not only what existed, but what might be done, T. E. Harrison, the Engineer to the Docks, decided to adopt the system of shipping by spouts.

4780.



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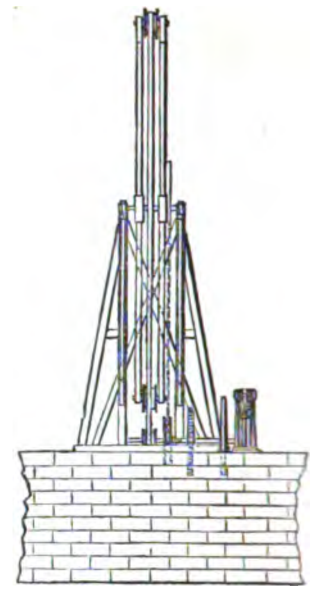

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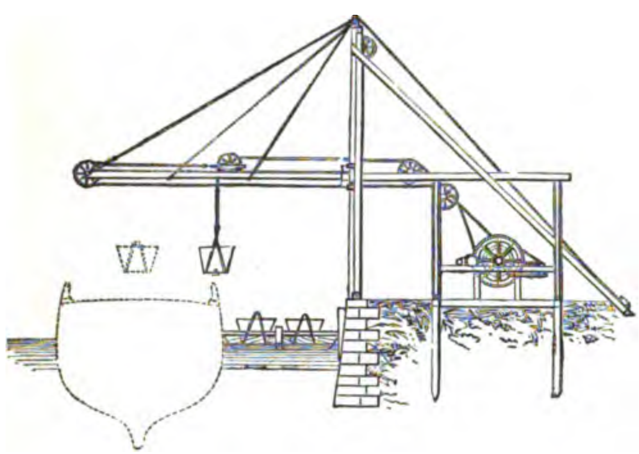

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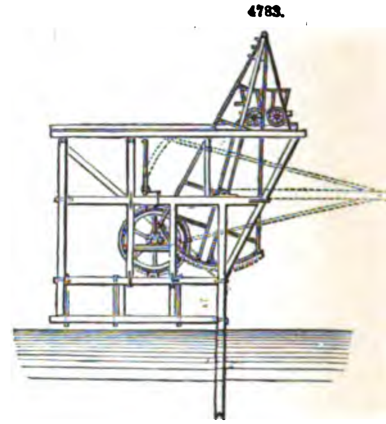
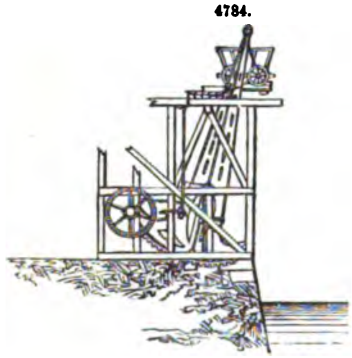
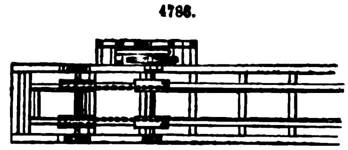


4784.



4786.



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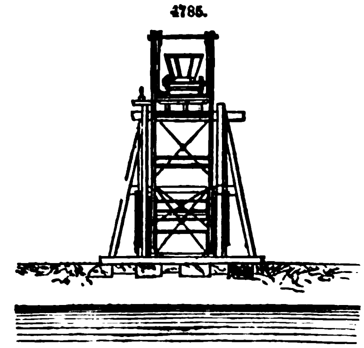
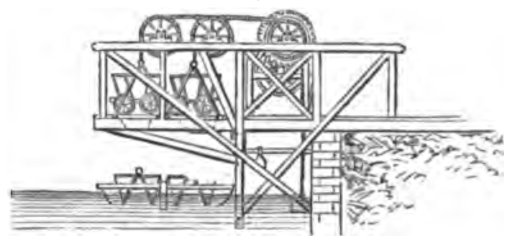


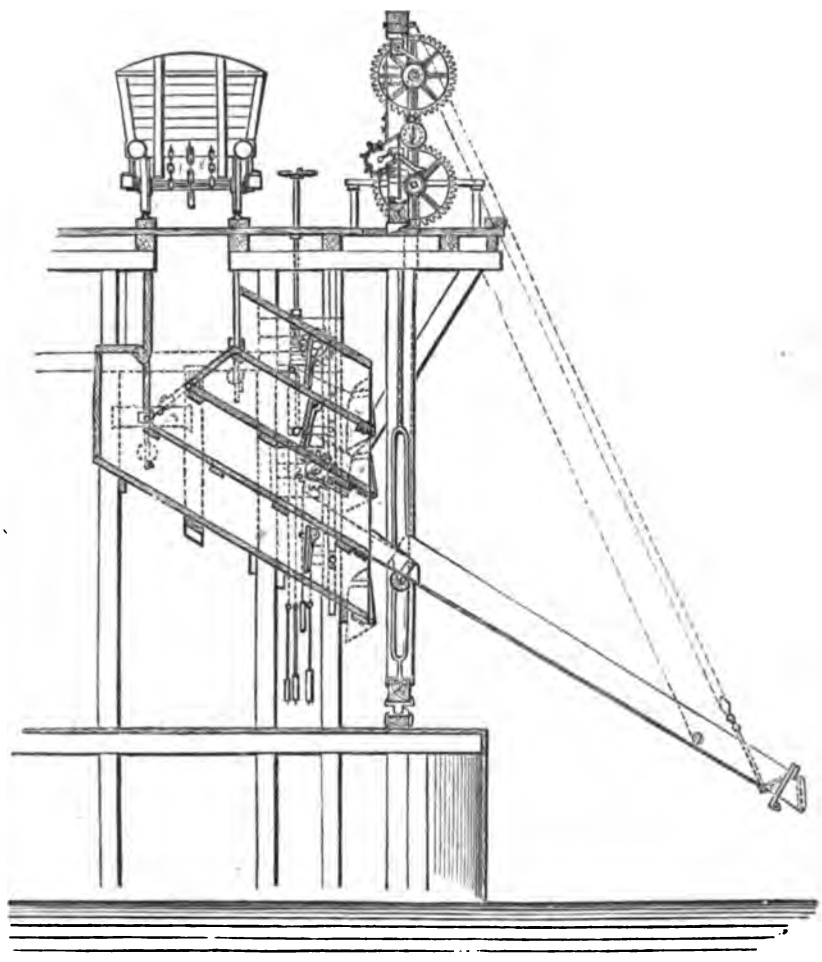
The arrangement of the spouts, and the mode of adjusting them to the level of the vessels, are shown in Figs. 4788, 4789. The variation in the level of the deck of a large ship when light, and at high water of a spring tide, and in the level of the deck of a small vessel, loaded, at a neap tide, is 20 ft., and it was necessary to provide for this difference.

In arranging the inclination of the spouts, it was essential to ascertain the angle at which the coals would slide on smooth iron plates without rolling. This was tested under a great variety of circumstances, and with every description of coal, when it was found that an angle of 50° would meet every circumstance. In order to allow for the varying level of the ship's

4787.



4788

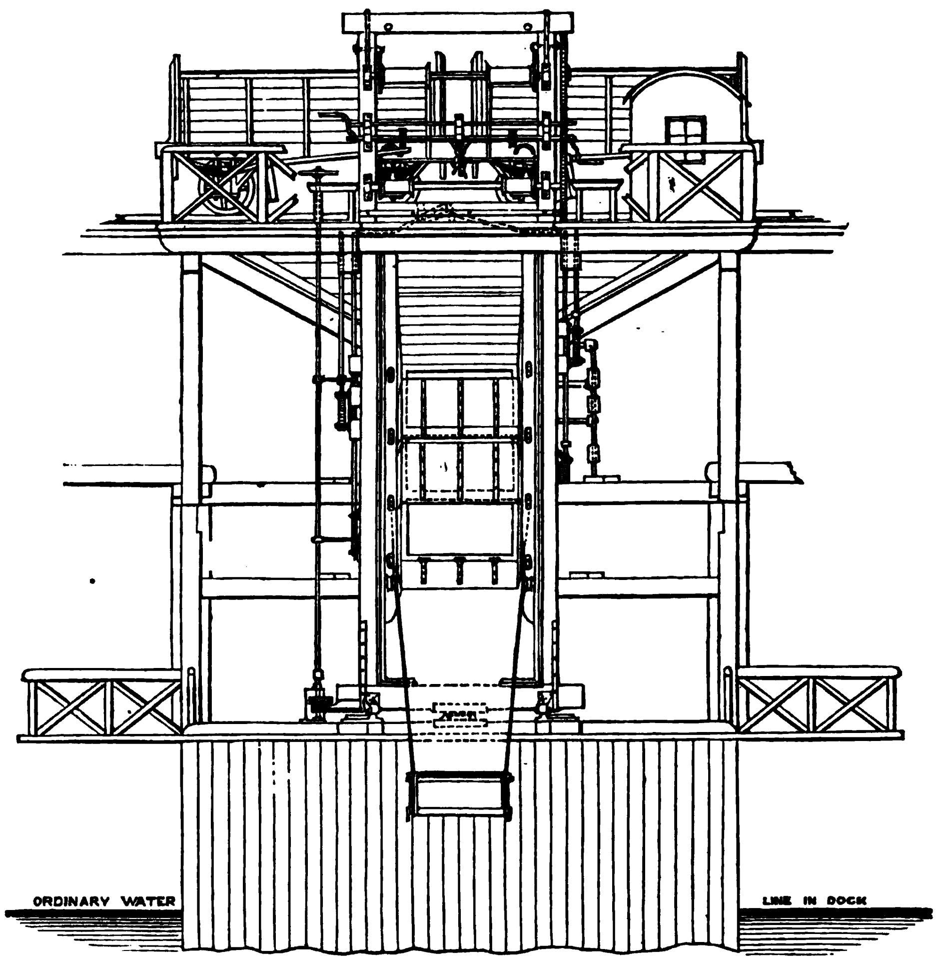


deck, arrangements are made to deliver the coals at four different levels. The difference of level not provided for is made up by giving a greater or less inclination to the spout. For a very large vessel, a special drop is erected at the end; the wagons are brought immediately over a large hopper, sufficiently long for three chaldron wagons, or two 8-ton wagons, to be emptied at once. The coals are directed into any one of these divisions by the opening or shutting of trap-doors turning on hinges and well balanced, so as to be easily moved; the spout is also raised or lowered in guides, and is worked by winches, the men standing on the level at which they work when shipping coals. Traps are provided for regulating the descent of the coals into the ship. In some cases the spouts are made to slide in a frame turning on a pivot, the object being to give a greater range into the ship's hold, particularly with screw colliers, and thus to avoid the necessity of moving the ships. This part of

the arrangement has proved to be very useful. The moving of the spout having been found to be rather a heavy lift for the men, this is now in course of being remedied by the addition of counter-balance weights.

In practical working, when shipping coals, the plan adopted is to keep the spout as nearly full

4789



as possible, merely letting the coals slide sufficiently down to allow of the next wagon being teamed; so that though in the first filling of the spout, or on altering the level of the spout, the coals have a few feet to fall, yet this only applies to a small quantity of coal. Afterwards the whole mass descends slowly, and no further breakage takes place. When these points are carefully attended to, as little breakage takes place by this system as by any other.

The jetties on which these shipping places are erected, Figs. 4790 to 4793, are carried out into the dock at the end next to the standage-ground for coals. Each shipping jetty has ten shipping places. These shipping places are 100 ft. from centre to centre, and are so arranged that the vessels overlap each other. This plan has been found to work very well in practice. The lower portion of the timberwork of the jetties is thoroughly creosoted. That above the level of the quay is kyanized. No timber is used in any situation about the dock works which is not either creosoted or kyanized.

In making these different arrangements, the saving of manual labour has been a primary consideration, and gravity has been called into operation to the utmost possible extent. The plan and section of the standage-ground, Figs. 4794, 4795, show the general arrangements, and afford a good idea of the mode by which the working is carried on. The sidings from A to B are those into which the locomotive engines bring their wagons, and are on an inclination of 1 in 132. From these sidings the wagons are sorted by gravity into one or other of the fourteen sidings between B D. The two centre lines are reserved as travelling lines for coals going directly on arrival to the jetty for shipment. This sorting, from the point where the locomotive leaves the

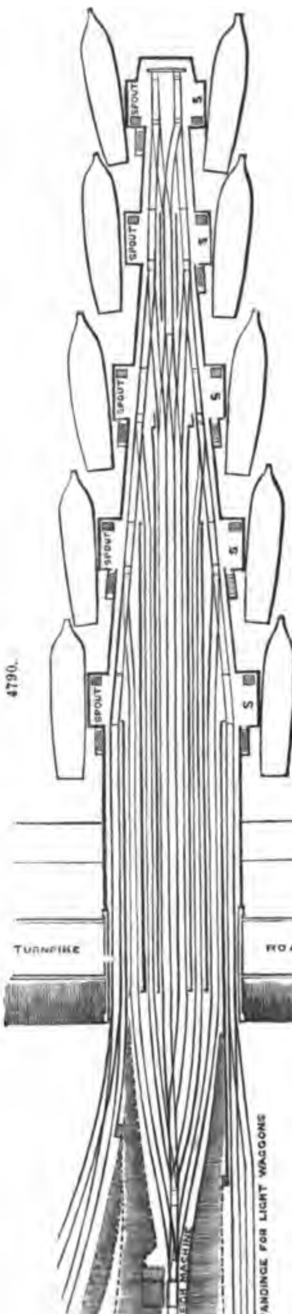
wagons, into the different sidings, is for each jetty attended to by two operatives, one of them also attending to the switches. These general sidings are all on an inclination of 1 in 132, and at the switches and curves of 1 in 66. When the wagons are wanted for shipment, they are brought out of the sidings, and descend by gravity under the charge of men, who deposit them as near as possible to the spout. In order that coals from any one siding may go to any one spout, all the lines from these sidings are brought into one line at E, Figs. 4794, 4795, at which point they pass over a weighing machine. When passing over this machine, at a rate not exceeding two miles an hour, the weights are easily taken. Immediately after passing over the weighing machine, the lines branch out to the various spouts, and the wagons are directed into their proper roads by switches, the working of which is attended to by a man. The handles for working the switches are all brought to one focus, at the weighing machine, by means of rods. There is a considerable amount of standage provided for each spout, the standage being on inclinations varying from 1 in 132 to 1 in 100. Where the wagons descend from this standage to the spouts, the inclination varies from 1 in 20 to 1 in 87. The principle on which these shipping jetties are constructed is, that all the wagons are emptied, and are then returned along two lines, one on each side of the jetty. These lines are on an inclination of 1 in 100. The impetus of the loaded wagons in descending, carries them up this gradient, to or beyond the places where they are to be emptied; and when emptied, gravity takes them away.

It was originally contemplated only to run three chaldron wagons, or two 8-ton wagons, down at a time; but experience has shown that twelve chaldron wagons, or six 8-ton wagons, may be taken with safety. In this case they are all run past the hopper, then drop back by gravity, and are emptied three, or two, at a time, as they pass over the spout, without being uncoupled. Great expedition results from this arrangement.

When a portion of a train of wagons is run down to the spouts, from the standage immediately adjoining, the remainder of the train follows by gravity; and it is necessary that it should be stopped by a quickly-acting chock. For this purpose a chock has been constructed of a somewhat novel kind, which works very well. The man in charge of the wagons first uncouples the number he intends to run down. He then lifts the lever, and the whole train descends by gravity. The moment the last wheel of the uncoupled set passes the chock, he lets the lever fall, and goes on himself with the uncoupled set, braking it down the steep incline; the remainder of the set being arrested by the chock.

The difference of level also of the crossing rails, between the loaded and light lines, is about 15 in. To meet this a system of sliding rails has been adopted, and is found to work well. The loaded wagons in their descent close the sliding rail, to allow them to pass over, and it is opened again by balance-weights, to admit of the passage of the empty wagons.

4790.



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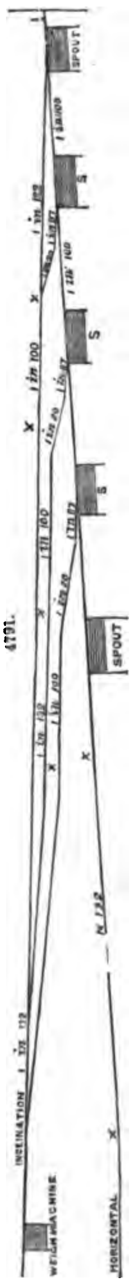
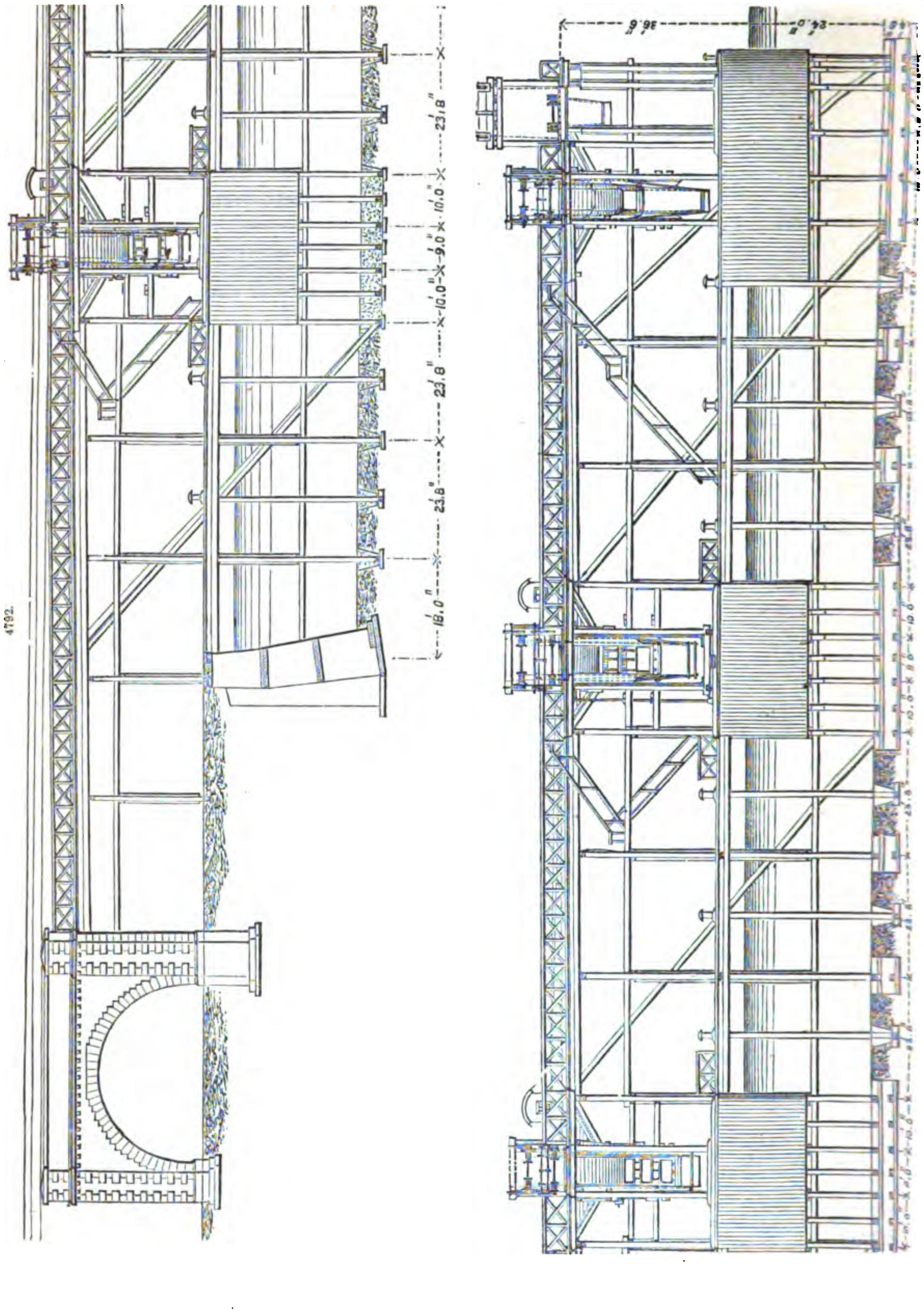
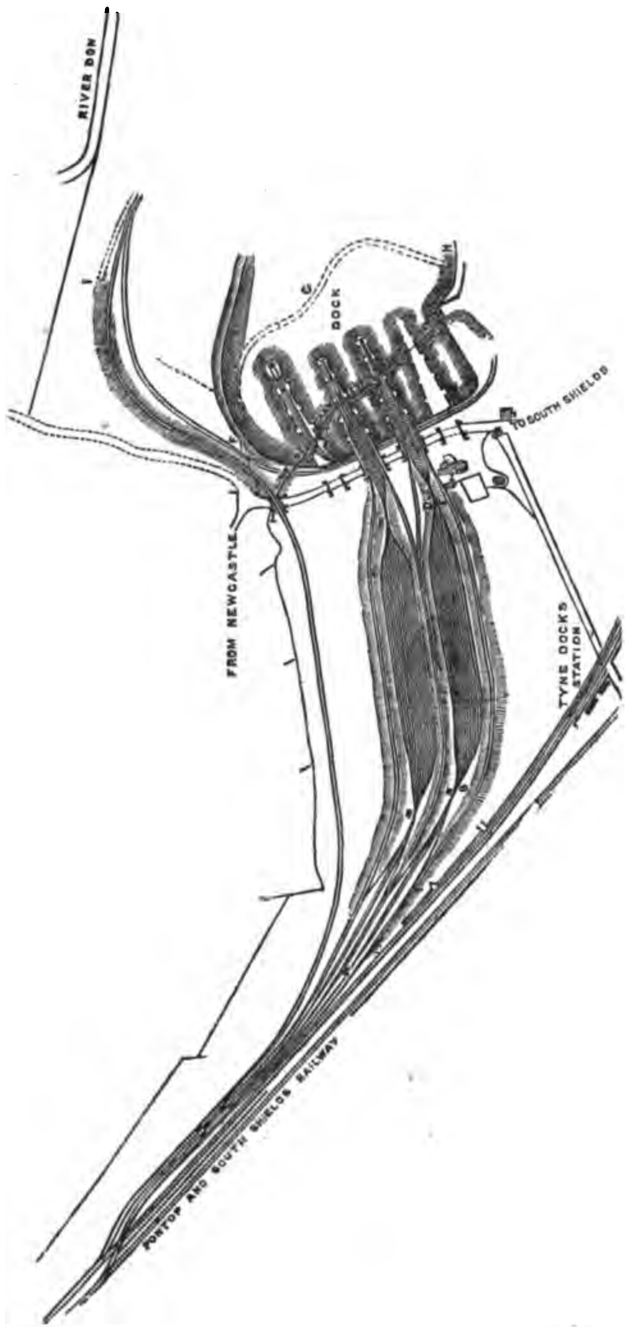


Before deciding on the inclinations to be given at different portions of this self-acting system,

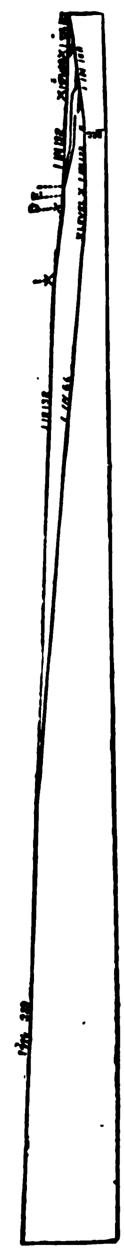

4792.
23' 8"
10' 0"
9' 0"
10' 0"
23' 8"
23' 8"
18' 0"
36' 6"
24' 0"

lengthened experiments were made on the ground above, where a complete plan of the proposed arrangement, for one spout, was laid down; and on it, wagons of all classes in use were tried, under different states of weather and circumstances. The result was that the inclinations adopted, which are much steeper than theory would give, were found to be necessary.

4794.



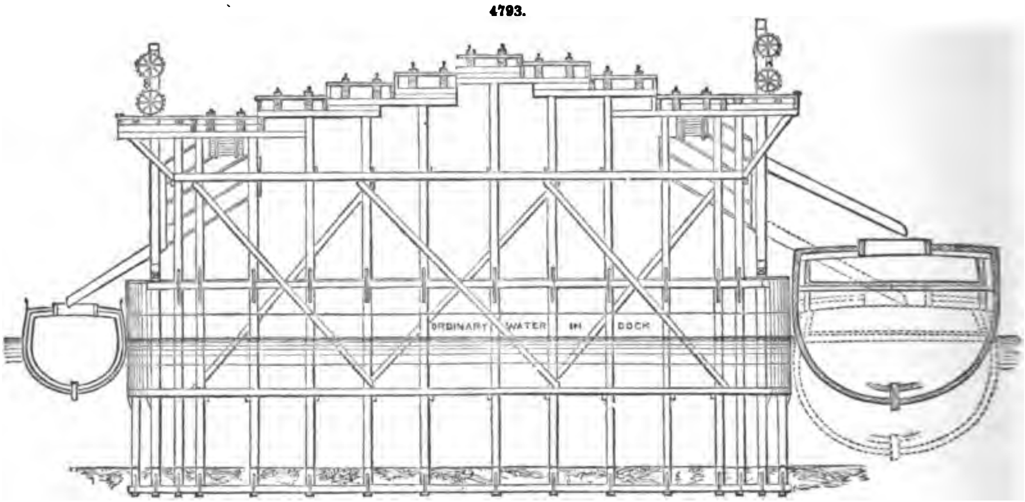
4795.



The quantity of coals shipped at South Shields, by the North-Eastern Railway Company, in the year 1858, was 1,203,524 tons. The number of collieries shipping coals to the Tyne Docks at that time was sixty-six. The coals from these collieries were divided into 227 different sorts;

and although these did not all come down at the same time, yet the necessity is at once obvious for the large amount of standage-ground and the number of lines of railway which have

4793.



been provided. The length of single line of rails for each jetty is six miles. See Transactions Inst. C. E., vol. xviii.

KEY.

The word key is applied in the arts to anything that fastens, as a piece of wood in the frame of a building, or in a chain. Also any instrument which serves to shut or open a lock by being inserted into it; and made, by turning, to push its bolt one way or the other. In architecture, a piece of wood let in another across the grain to prevent warping, is called a key; so also is a piece of wood used as a wedge; or the last board of a floor when laid down. In masonry, the highest central of an arch is the key-stone. In machinery, a key is a piece of wood, often wedge-shaped, placed in coincident slots or mortises to hold parts together; a cotter, as in Fig. 2361.

A key-seat is a rectangular groove, especially in a wheel and shaft, to receive a key so as to prevent one part from turning on the other; it is frequently called a key-bed or a key-way.

KILN. Fr., *Four;* Ger., *Ofen;* Ital., *Fornace;* Span., *Horno, Calera.*

The words kiln, oven, and stove, are often used synonymously, but although all three are appliances for the application of heat to certain industrial purposes, they differ essentially in their construction and operation. A kiln is a structure of considerable size, which may be heated for the purpose of roasting, burning, hardening, annealing, or drying anything; as a *kiln* for annealing porcelain, a *kiln* for burning lime.

An *oven*, a place, arched over with brick or stone-work, for baking, heating, or drying; hence any structure, whether fixed or portable, which may be heated for baking or like uses.

A *stove*, an apparatus variously constructed, which is heated by fuel or gas, for warming a room or building, for heating the blast of a furnace, for culinary or other purposes.

Figs. 4796, 4797, show Wm. Goreham's annular kiln for burning cement, constructed with a hollow chamber forming a movable partition across the kiln, the chamber having tubes projecting from it into the kiln, and being also formed to conduct the products of combustion from the flue on one side of the kiln to the other and to the central chimney.

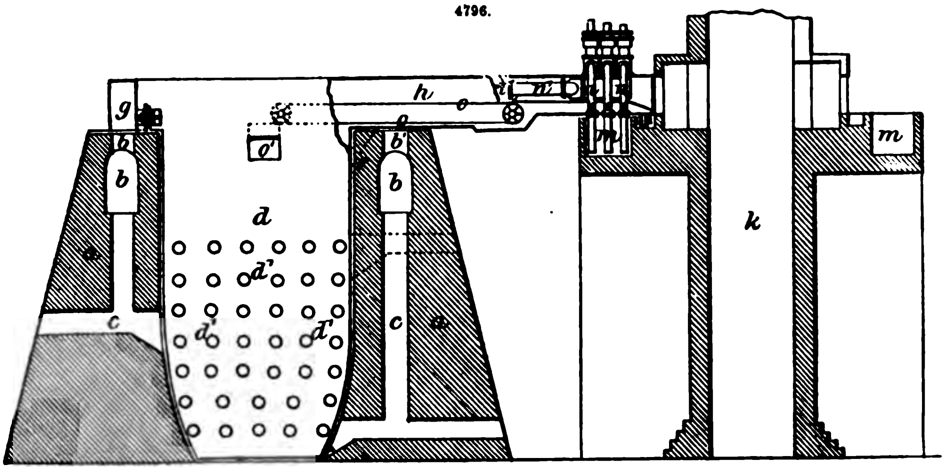
Fig. 4796 a vertical section of part of the kiln, and Fig. 4797 a plan partly in section. *a a* is the body of the kiln; *b b*, horizontal flues carried around the upper part of both sides of the kiln; *c c*, vertical flues leading down from the flues *b*, and communicating with the interior of the kiln; *d d*, the movable hollow chamber forming a partition across the kiln, and having tubes d^1 projecting from it into the kiln. The partition is of wrought iron and is carried by rollers *e*, which run upon rails *f f*, fixed around the top of the side walls of the kiln; *g g* are flues extending from the top of the hollow chamber to connect two or more of the passages, b^1, b^1, which lead from the flues *b*, with the hollow chamber; *h* is a flue from the top of the hollow chamber by which the gases are led away to the central chimney *k*. The extremity of this flue where it abuts against the chimney is supported on rollers running on a fixed rail *l*.

In the arrangement of this kiln the slip is dried by being forced in the form of spray or minutely divided into and amongst the heated gases as they pass from the kiln to the chimney. The slip is fed into the annular trough *m*, from which it is pumped by the pumps *n* which are carried within the flue *h*. The suction-pipes of these pumps are perforated, so that a large amount of heated gas is drawn into the pumps together with the slip, and thus the slip as it is ejected by the pumps through the tubes n^1 will be dispersed in a fine spray, or it might be caused to pass through a number of small orifices. The slip issuing from the tubes n^1 comes against the fixed plate n^2 and drops on to the endless chain or band *o*, by which it is carried forward to the centre of the travelling hollow chamber *d*, and dropped into an inclined trough or shoot down which it slides and falls into the kiln through an opening o^1 at the end of the shoot.

This opening is fitted with a hinged flap, by which it is closed, except at the time when dried material is passing through it.

When the kiln is at work the hollow chamber *d* is from time to time moved a distance forward and away from the burning material, and the slip or dried material is fed into the kiln just in rear

4796.



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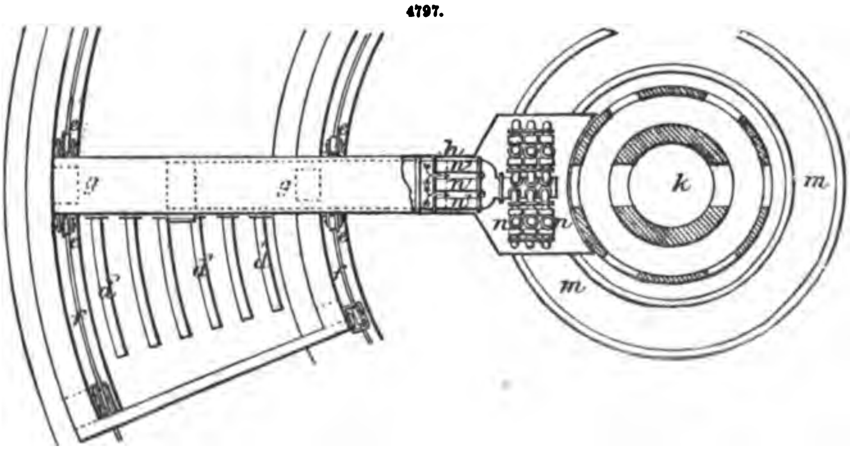


of the hollow chamber and on to and between the tubes d^1 projecting from it, the requisite quantity of fuel being at the same time fed in at top of the kiln. The fire is thus led gradually and continuously around the kiln.

In kilns for burning bricks and similar articles, C. G. Johnson constructs a flue running along the back end of a range of end-firing arched kilns or ovens, known as Newcastle kilns, and instead of placing a chimney on the end farthest from the fire, places it at the end next to the fire. A communication having been formed between the kilns by the flue running along the back of the range, it is so regulated by suitable dampers, that when firing any kiln in the range the heat can be drawn from it through any other kiln from back to front by the chimney placed for that purpose on the front end of that other kiln. The chimney on the kiln which is being fired is closed with a suitable damper.

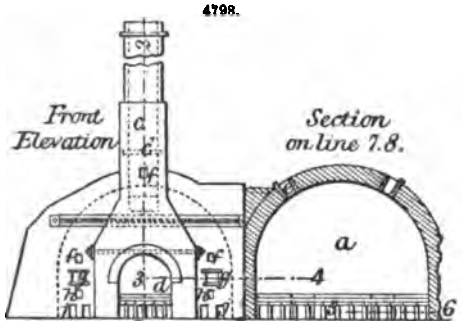
One large chimney placed in any convenient position may be used in common by all the kilns in the range in place of each kiln having a separate chimney. In this case each kiln is connected with the chimney by means of a suitable flue at the end next to the fire. Each such flue is provided with a damper.

Fig. 4798 is a front elevation, partly in section, of a portion of a range of kilns thus constructed; Fig. 4799 a longitudinal section; and Fig. 4800 a plan, partly in section. In Fig. 4799 the section is taken on the line 1, 2.

a is the body of the kiln, where the bricks are stacked on a plane floor; *b*, a flue that connects any two or more kilns with each other, the communication being regulated by means of dampers b^1, b^{11}; *c*, chimneys with dampers c^1; *d*, an archway for setting and drawing the kilns, made up with bricks daubed with mud or clay, so as to seal it air-tight whilst the bricks are burning; *e e e e*, holes for cooling off the kilns after ceasing to fire, or when the bricks are completely

burnt; these holes are closed up whilst the firing is proceeded with; *f f f*, sight-holes to watch progress of the burning; *g g*, firing holes; *h h* and *j j*, stoke-holes for stoking the fires and breaking

4798.



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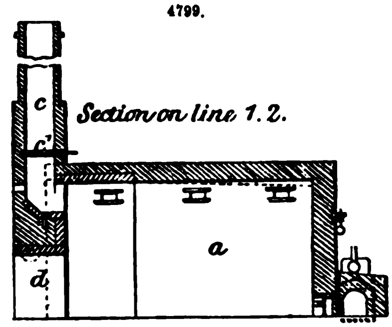

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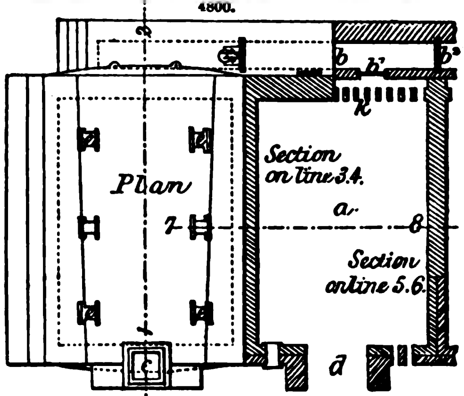


up clinkers; *k k*, flue-holes for spreading the draught, which is carried through dampers b^1 into the flue *b*, thence on to any other kiln as required.

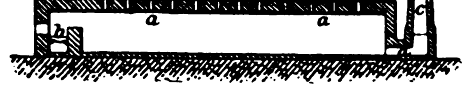
The system of firing is the same as in the ordinary end-firing ovens. The fire is first made up in the bottom holes *j j*, and gradually worked up until it reaches the top of the hole *g*; the heat passes through the bricks, which have been previously dried by the heat from any other kiln, and through the dampers b^1 into the flue *b*, and then it is directed by means of the dampers b^1 and b^{11} to any kiln in the range set with green bricks; the heat traverses this kiln, and thence escapes through the chimney *c* on the same kiln. Care is taken that the damper c^1 in the chimney *c* of any kiln that is being fired is closed.

The mode of working is as follows:—No. 1 kiln upon being fired is put in communication with No. 2, this latter having previously had the opening in front closed up and the damper in the chimney opened. Thus No. 2 kiln acts as a chimney to No. 1 during the time that the moisture is being driven off the bricks in No. 1; whilst this operation is going on No. 3 kiln can be set, and as soon as the moisture is expelled from No. 1, communication with No. 2 kiln can be closed and that with No. 3 opened; the waste heat from No. 1 will then pass into No. 3 and be drawn through the green bricks by the chimney in front, the damper in it being opened; No. 1 is now finished off by firing in the usual way. The moisture in No. 3 kiln having been driven off by the waste heat from No. 1, the damper in its chimney is closed and communication effected with any other kiln in the range set with green bricks. Thus the waste heat is constantly passed forward, and the only coal expended on any kiln is that required to finish off the burning after all the moisture has been expelled, and it is found that about one-half the coal consumed in ordinary end kilns is expended in effecting this.

It will be seen that there is no difficulty in timing the operation so as always to have a kiln ready to receive waste heat, as it is competent to direct the waste heat from any one to the other, or to be firing more than one and passing waste heat through one only, or firing one and passing the heat through more than one, or burning several and passing waste heat through several at once, according to the quantity of work being turned out; it will also be seen that in these kilns there is no danger of driving moisture from the burning bricks to the green ones, as in the case of other designs which have been introduced with the object of economizing waste heat, and that the well-known value of end kilns for producing the soundest articles is therefore unimpaired. The fresh-stacked bricks in these kilns not being immediately exposed to the direct action of the fires are less liable to crack, as the moisture remaining in the bricks when taken from the stoves is gradually expelled by the waste heat from one or more of the other kilns, and consequently the bricks are sounder and there is less waste than in ordinary kilns.

Hoffmann's Kilns.—Fig. 4801 represents a longitudinal sectional elevation of a kiln on Hoffmann's system, as arranged by Chamberlain, Craven, and Wedekind, constructed in a straight line. *a* is the brickwork of the kiln, *b* the fire-place at one end, the opposite end opening into a chimney *c* by a flue *d*. A number of openings *e e* provided with close-fitting lids or covers are formed at suitable intervals along the roof of the kiln, such openings being intended for the introduction of small fuel. The entire length of the kiln having been filled with bricks in a fit state for burning, a fire is lighted in the fire-place *b*, and air allowed to enter freely through the fire-door. So soon as the heat at this end of the kiln is sufficiently great to

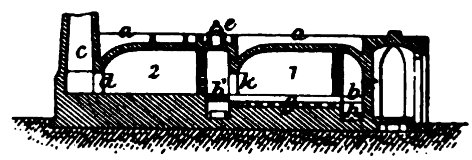
4801.



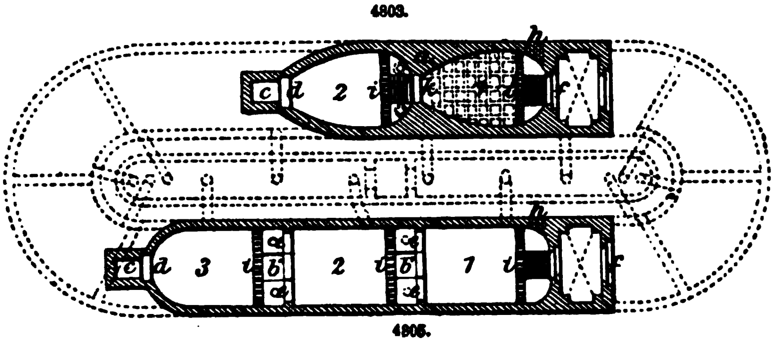
ensure the combustion of fuel introduced from the top, the supply of fuel is then commenced through the openings *e e*, and the heat maintained at the temperature requisite for burning the bricks. The hot air and products of combustion pass along the entire length of the kiln between the goods stacked in it, gradually heating them, and finally pass off by the flue *d* to the chimney *c*. So soon as that portion of the stacked bricks into and amongst which the fuel has been supplied has become sufficiently burnt, the further supply of fuel is stopped, and the supply is then carried on through other openings *e* in advance, so as to mingle the fuel with the adjoining bricks, which by this time will be sufficiently heated to ensure the combustion of such fuel. Those bricks which have been thoroughly burnt are now allowed to cool gradually by the action of the cold air which passes amongst them and takes up caloric, which is transferred to the succeeding bricks on its way to the chimney. In this manner the process of burning is continued until the extreme end of the kiln has been reached, some of the goods having in the meantime been drawn and replaced by fresh ones, so that the kiln will be ready for relighting by the time the last of the goods is withdrawn. These kilns may be provided at intervals with sliding doors which extend across the kiln, and subdivide it into a number of separate compartments; facility is thus afforded for making use of these compartments as drying chambers, whilst the other portion of the kiln is burning. The drying may be facilitated by bringing hot air from the cooling portions of the kiln into the drying chamber for the time being by means of a movable pipe or flue, which may be adjusted to any of the holes *e* in the roof. When the bricks are sufficiently dry, the doors and flue are removed so as to bring them within the direct range of the hot air and products of combustion from the burning bricks preparatory to their being fired from above. In this arrangement flues provided with dampers should be employed leading from each compartment to separate chimneys, or to one common flue leading to a single chimney, and each compartment should have near its upper part a flue for carrying off the steam and vapour evolved during the process of drying.

Fig. 4802 is a section, and Fig. 4803 a plan of a pottery kiln made in two compartments; Fig. 4804 a longitudinal section, and Fig. 4805 a plan of a similar kiln made in three compartments; any number of compartments may be used in these kilns, but they are built in a straight line, and have no continuity of action. *a* is the brickwork of the kilns; *b*, b^1, b^{11}, are fire-places for heating the several compartments 1, 2, and 3; *c*, a chimney common to all the compartments; and *d*, a flue or aperture opening direct into the chimney from the last compartment of the series; *e e* are openings in the roof of the kiln provided with close-fitting lids or covers for the introduction of the fuel into the fire-places b^1, b^{11}, which heat the compartments 2 and 3. The front compartment is heated by the furnace *b*, which is supplied with fuel through the door *f*. The several furnaces or fire-places may be provided or not with grate-bars as required. *g* is an air-flue extending beneath the floors of all the compartments excepting the last of the series, and communicating with the ash-pits of the several furnaces or fire-places; *h h* are openings for the entrance of fresh air into the ash-pits, and thence to the flues *g*. In using these kilns both or all the compartments are filled with the pottery to be burnt; a perforated wall of fire-brick *i* is then constructed between each furnace and its corresponding compartment, to prevent the ashes from coming in contact with the ware. A fire is now lighted in the furnace *b*, and the hot air and products of combustion pass through the several compartments

4802.

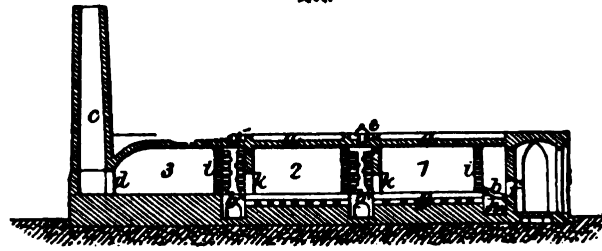


4803.



4805.

4804.



on their way to the chimney, heating the whole of the ware in the compartments which communicate with one another by the openings at *k k*. So soon as the ware in the first compartment 1 is sufficiently burnt, the door of the furnace *b* is closed so as to exclude air, and the fire-bars are carefully covered over with earth. The air-inlets *h h* are now opened so as to admit the air along the flue *g* to the furnace b^1, the heat in which escaping from the compartment 1 is sufficient to effect the combustion of the fuel which is supplied to it through the opening *e* above. The second compartment 2 is fired whilst the ware in the first compartment is gradually cooling. When the wares in the compartment 2 are burnt, the furnace b^{11} is lighted in the same way as the furnace b^1, and air supplied by the flue *g* as before, the process thus continuing step by step until the whole of the compartments have been fired, by which time the goods in the first compartment will be ready to be withdrawn. Above the furnaces b^1, b^{11}, a number of projecting bricks are built in the walls so as to catch the fuel as it is thrown in from the top, and thus ensure a uniformity of heat throughout the full height of the furnace.

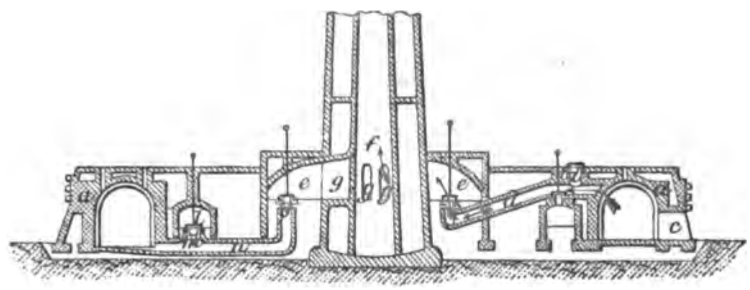
Fig. 4806 represents a vertical section, and Fig. 4807 a sectional plan, of a continuous kiln combined with a second or inner annular chamber, by which dry or warm air may be taken from any of the heated chambers of the kiln to any of the other chambers, for the purpose of drying green bricks or other articles from which it is desired to drive off the moisture. *a*, the brickwork of the kiln, a portion of the annular burning and drying space of which may be shut off or separated from the rest by two movable diaphragms *b*, b^1, to form a drying chamber. The entire kiln is capable of being subdivided into a number of compartments, numbered in Fig. 4807 from 1 to 12 inclusive, although any other number may be used. Each compartment is provided with a door at *c c*, through which the goods are introduced and removed. From the upper part of the several compartments extend a series of flues *d*, converging towards and opening into an annular smoke-chamber *e*, which surrounds the chimney *f*, and communicates therewith by the passages or openings *g*. The inner ends of these flues inside the smoke-chamber are closed or left open by means of conical plugs *h*, which, by being elevated, will regulate the amount of opening of the flues. A closed man-hole *i*, Fig. 4806, is made in each of these flues for the facility of cleaning. Valves *k* connect any one of these flues when open with the annular passage *l* for dry or warm air, the bottom of the passage communicating by means of valves *m* with the flues *n*, which lead from the lower portions of the compartments of the kiln to the smoke-chamber *e*, before referred to. These flues *n* are also provided with conical plugs or dampers *o*, similar to those which are fitted on to the inner ends of the flues *d*.

In Fig. 4807 the chambers 3 and 4 are represented as being shut off from the rest by the doors *b*, b^1, and are supposed to contain green bricks; the chamber 5 is being filled whilst the goods are being removed from the chamber 6. The chambers 7, 8, 9, and 10, all contain burnt goods in the act of cooling whilst the chambers 11 and 12 are being fired, the hot air therefrom passing through the goods in the chambers 1 and 2, and being obstructed by the door *b* from entering the drying chambers 3 and 4 direct, it passes off by the bottom flue n^1 of the series direct to the smoke-chamber *e*, and thence to the chimney, the plug or damper o^1 being more or less open for that purpose according to the draught required. The fresh air enters by the open doors c^1, c^1, passes through the heated goods in the chambers 7, 8, and 9, thereby cooling the goods, and at the same time taking up caloric. A portion of this air so heated passes onwards through the chambers 10, 11, 12, 1 and 2, and thence by the flue n^1 to the chimney, whilst another portion enters one of the flues *d* at the mouth thereof d^1; and as the plug or valve h^1 on the inner end of this flue is closed, the heated air enters by the open valve k^1 into the annular chamber or passage *l*. The warm air then traverses the chamber *l*, passes through the only open valve m^1 of the series into the flue n^{11} of the series, the end of which in the smoke-chamber is closed by the valve o^{11}, and thence to the drying chamber 4 and chamber 3, and finally escaping at d^{11} by the flue d^{111} and open plug or valve h^{11} into the smoke-chamber *e* and chimney *f*. The whole of the valves *h*, *o*, *k*, and *m*, are kept closed, except those which are in connection with the flues for the time being, and so soon as the goods in the drying chambers 3 and 4 are sufficiently dry for burning, the doors *b*, b^1, are removed, and replaced at b^{11}, b^{11}, exposing the bricks in the chamber 3 to the direct action of the heat from the kiln fires, whilst the chamber 5, just filled with green bricks, forms with the chamber 4 a drying chamber. A fresh set of valves or dampers is now opened, and the operations of burning and drying proceed in a continuous manner.

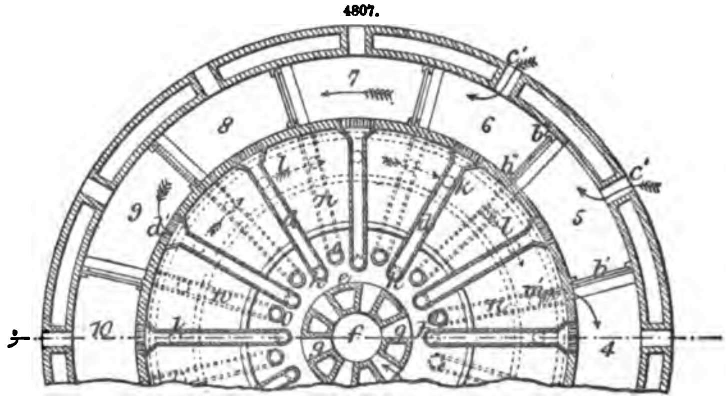
Figs. 4808, 4809, are respectively a vertical and horizontal section of a similar kiln provided with a separate collecting flue and chimney for the abduction of the steam evolved during the drying of the green bricks. In drying green bricks, the quantity of steam evolved, which varies periodically, sometimes impedes the draught, more or less, when allowed to mix with the gases of combustion; but the inconvenience is remedied by leading off the steam by separate and distinct passages, so that it does not mix with the gases of combustion until both have ascended some distance up the chimney; this is accomplished by using a separate steam collector *p* communicating by passages *q* with an internal steam-chimney *r* built inside, and extending a convenient height up the chimney, so that the steam and products of combustion are not allowed to mingle with each other till they arrive nearly at the top of the chimney.

In Figs. 4808, 4809, the hot air for drying the bricks enters the chambers 3 and 4 in the manner described in reference to Figs. 4806, 4807, but in place of passing off with the steam into the smoke-chamber *e*, they are conducted by the passage *d* and valve *h* into the steam-chamber *p*, and thence into the internal chimney or tube *r*, whilst the gases and products of combustion pass off by the flue *n* and valve *o* into the smoke-chamber *e*, and thence by the passages *g* into the chimney *f* surrounding the tube *r*; in all other respects this kiln is worked in a similar manner to the kiln shown at Figs. 4806, 4807. If desired the slits or openings in the arches of the annular burning chamber of these kilns or ovens for the admission of the interrupting doors or dampers *b*, b^1, may be dispensed with by placing the entrance *c* to each compartment at the end next the door or damper instead of in the centre of the compartment, as in the Figs. 4806 to 4817, and by having

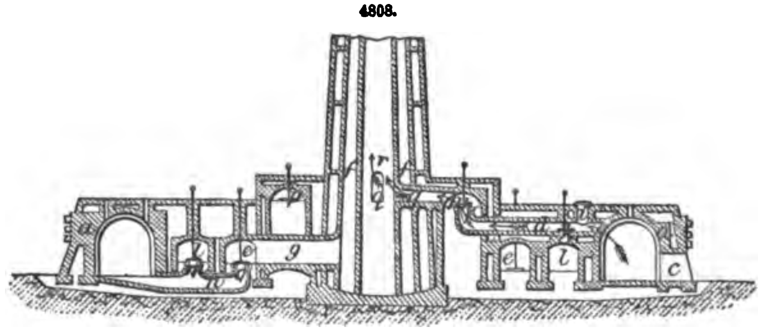
4806.



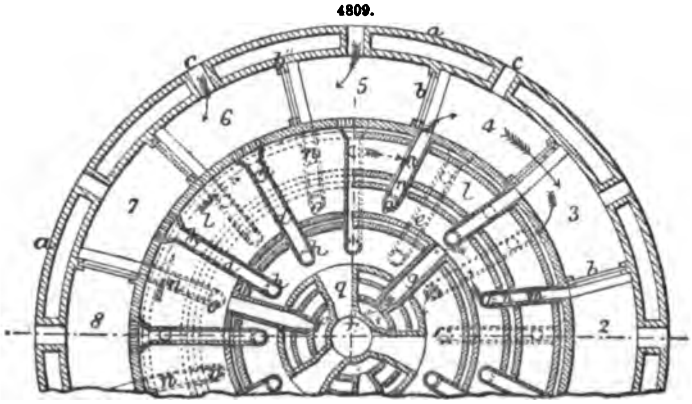
4807.



4808.



4809.

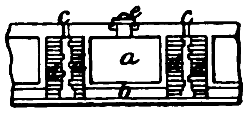


the doors or dampers made up in several parts, each small enough to be introduced through the entrance *c*; by this means the doors *b*, b^1, may be inserted or removed by hand through the same apertures by which the kiln is filled and emptied.

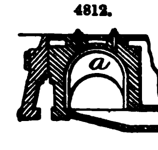
In the burning of pottery and other ware which is required to be protected from direct contact with the fuel and products of combustion, the compartments may be constructed as in Figs. 4810, 4811. In this case a closed chamber *a* is built inside each compartment, but having a free passage *b* along the sides and under the bottom for the circulation of the heat and products of combustion. The fuel is fed in from the top through apertures *c*, and is kept loose and open by falling amongst the projecting bricks built in the sides of the fire-chamber, as shown at *d*. A man-hole *e* is formed on the roof of the chamber *a* for the introduction and removal of the ware, this hole being provided with a close-fitting lid or cover.

Figs. 4812, 4813, are a transverse and longitudinal section of a portion of a kiln intended for burning limestone and other substances which are liable to shrink considerably during the process of burning. As this shrinkage or falling of the substances would leave a void space between the roof and the surface of the substances, the hot gases or products of combustion would, if not checked, pass over the top of in place of amongst the substances. To obviate this defect, an arch *a* is built so as to extend downwards from the roof between each compartment sufficiently far to present a barrier to the gases passing along the surface of the substances, and compel them to descend into and amongst such substances when passing under each arch. Another mode of accomplishing the same object is shown at Figs. 4814, 4815, where the chamber of the kiln is composed of two side walls *a* only, with arches at intervals, the substances being covered over between these arches by a covering of loam and earth *c*, which descends with the shrinkage of the substances.

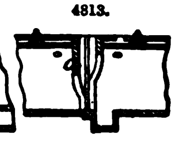
4810.



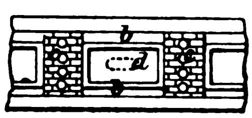
4812.



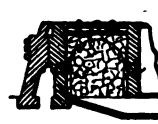
4813.



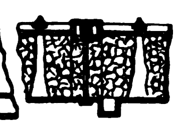
4811.



4814.



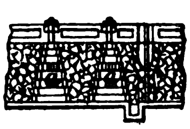
4815.



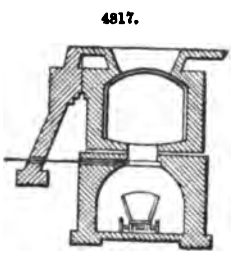
In treating those materials which lose altogether their original form, and fuse or melt to a mass when subjected to a great heat, the fire-places of the kiln must be enclosed by an open setting of fire-bricks or tubes *a*, Fig. 4816, the choking up of the fire-places will then be prevented. The doors or openings for introducing the goods or materials to be burnt in the kilns may be made either at the top or sides of the compartments or kiln-chamber; in some cases, as in the burning of limestone, it will be found advantageous to make the discharging holes in the bottom, and to have a tunnel or passage beneath, along which trucks or wagons, Fig. 4817, may be run to receive the contents of the several compartments.

In a recent arrangement of Hoffmann's kilns they are adapted to a system of forced combustion, and the construction so simplified as to render them suitable for contractors or temporary works, while the steam and products are rapidly carried off and greater economy of fuel obtained.

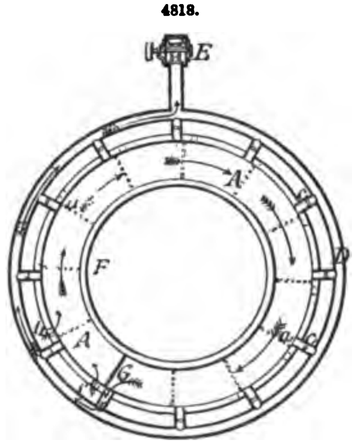
4816.



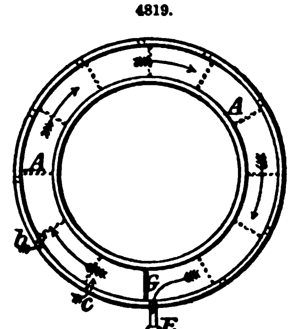
4817.



4818.



4819.



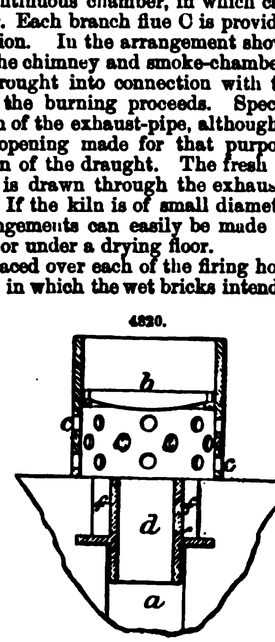
Figs. 4818, 4819, are sectional plans of a cheap construction of kiln intended to be worked on the continuous system, and specially adapted for the temporary use of contractors, or for erection on land containing only a thin seam of clay. In these modifications the construction of chimneys and smoke-chambers is rendered unnecessary, a forced combustion being maintained by the aid either of an exhauster or blower.

Each section of the annular chamber communicates by a branch passage or flue C with one

common annular flue D, leading to the exhaust-fan E, permanently connected with the flue D. Although the flue D and fan E are shown on the outer side of the kiln, they may be disposed in the central or internal space F enclosed by the said annular or continuous chamber, in which case the branch flues C would open from the inner wall of the chamber. Each branch flue C is provided with a damper, in order to guide the draught in the proper direction. In the arrangement shown at Fig. 4819 all flues and dampers are dispensed with, as well as the chimney and smoke-chambers. A is the annular kiln, and E a portable exhaust-fan, which is brought into connection with the different compartments or sections of the annular chamber as the burning proceeds. Special openings are made in the side wall of the kiln for the introduction of the exhaust-pipe, although if necessary each of the doors leading into the kiln may have an opening made for that purpose. G represents a closed partition, and arrows point out the direction of the draught. The fresh air enters by the openings *b c*, and after passing through the kiln A is drawn through the exhauster E along with the products of combustion in both arrangements. If the kiln is of small diameter, or the chamber A too short to completely absorb the heat, arrangements can easily be made for causing the heated air to pass through separate drying chambers or under a drying floor.

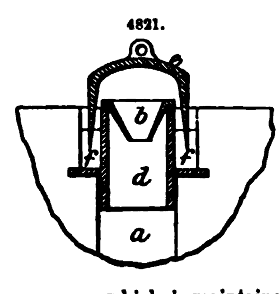
Fig. 4820 is a vertical section of a small fire-grate, which is placed over each of the firing holes in the roof of that part of the annular chamber of Hoffmann's kiln in which the wet bricks intended to be dried are deposited. *a*, one of the firing holes in the roof situate above that portion of the kiln which contains wet bricks; *b*, the fire-grate in which a fire is kindled. The down draught into the kiln draws in with it through the firing holes *a* a considerable amount of heated air and gases at numerous points, and as cold air is admitted through side openings *c c* below and surrounding the grate *b* it mixes with the hot air, and thus a series of currents of warm dry air enter through the roof of the kiln, and by circulating amongst the bricks effect their rapid drying.

4820.



Occasionally a loose or removable cone *b*, Fig. 4821, having a contracted mouth, resting on the top of an iron feed-pipe *d*, is fitted into the firing hole *a*. As the mouth of this cone is contracted to about 1 in. in diameter, it considerably diminishes the volume of cold air, which, when a strong draught is on, rushes down the firing hole so soon as the lid or cover *e* is removed, cooling the bricks, whilst on the other hand it serves to check the outward puff of gas and hot air which is liable to take place when, the draught being weak, a pressure of gas accumulates in the annular chamber of the kiln, involving not only a loss of heat, but a waste of fuel, and occasioning discomfort by causing the fuel to be blown up into the eyes of the stoker. The firing holes sometimes require to be used as air-inlets, as, for example, when they happen to be situate over that section of the kiln containing the bricks that are drying, therefore they cannot be permanently contracted, since the full size of orifice is necessary to afford free ingress of air, with a view to the more effectual drying of the bricks. As the cones *b* are loose, they may be readily removed when the holes *a* are required solely as air-inlets into the section containing fresh bricks. During the intervals of stoking or supplying fuel the firing holes with their cones are kept closed by the cap or cover *e*, which is maintained air-tight, or nearly so, by the joint *f*.

4821.



C. E. E. Muller has effected an arrangement of kiln for carrying out a mode of heating ceramic products continuously and progressively, and also utilizes Siemens' system of heating by gas.

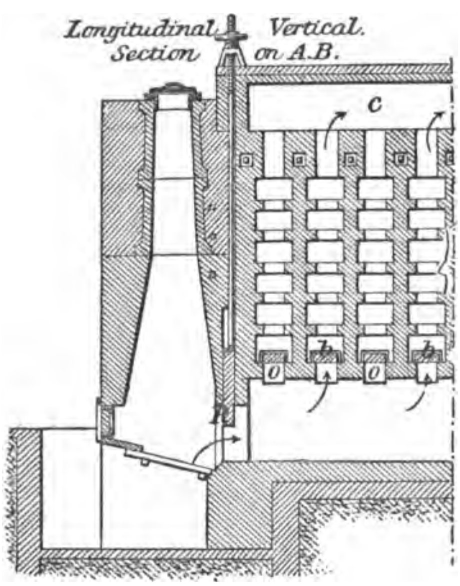
Muller's kiln, Figs. 4822, 4823, consists of a number of chambers separated from each other by perforated sides and bottoms, and disposed across the path of the flame. Through these chambers the articles to be burned or baked are passed along by pistons worked by mechanical means, so as to be gradually brought towards and into the hottest part of the chambers, and then by passing onwards to be as gradually conducted to the cooler end of the chambers; a small surface only of the bulk of the articles or substances so traversed through the chambers being exposed to the action of the flame, the process being thus progressive and continuous. The chambers are heated by gas generated in a gas-generating furnace; the flames play freely through the perforations, and after passing transversely through the chambers enter a heat regenerator, which serves to heat the air for supporting the combustion of the gases.

The length of the chambers, and the speed at which the articles or substances are caused to traverse through them, depend on the nature of the substances under treatment.

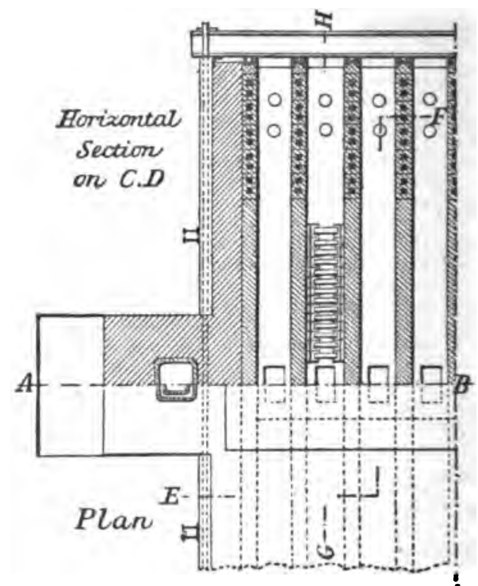
Figs. 4822 to 4824 show a kiln of this description, with a tubular heat regenerator. A vertical hopper is arranged at the front of the kiln; into this hopper the fuel is charged, and by an arrangement similar to that at p. 2089 is converted into carbonic oxide. The fuel may be supplied at long intervals, which is a considerable advantage. The surface of the fire-grate is so calculated that a slow draught is obtained, and the combustion of the fuel being slow, ashes only are formed instead of scoria; the attention required by the fire is thus reduced to a minimum. The fire-grate is also so arranged as not to admit of the ingress of air into the passage until it has traversed a great thickness of fuel. Carbonic oxide therefore only passes into the conduit marked with an arrow in the section. O are the openings for the outlet of the carbonic oxide from this passage, Figs. 4822 and 4824.

At each side of the passage there is another passage, shown rectangular in Figs. 4822 and 4824, and when heated air passes through oblique conduits *a*, which correspond to the openings O, a

4822.

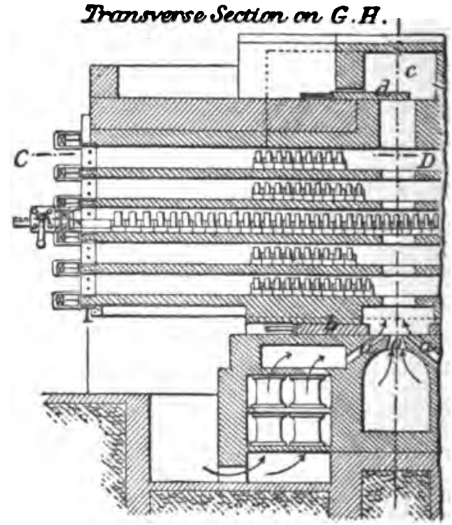


4823.



4824.

Transverse Section on G.H.



mixture of air and carbonic oxide is produced; the combustion is continuous when once the kiln is in operation, and in order to start it, it may be readily fired. The arrows show the admission of air. The space above serves for the expansion of the flame. *b* are the dampers on each side for regulating the admission of air. The admission of the carbonic oxide from the passage may also be regulated with facility by means of a damper. A damper R[1], either vertical or horizontal, could be readily applied.

Fig. 4824 illustrates the operation of the kiln. The products to be baked or burned are disposed on small carriers composed of refractory clay, which are in contact with each other, and are propelled by suitable apparatus a distance of 3 to 4 in. at a time. As the products advance towards the centre of the kiln, which is perforated at the centre of the passage, leaving at each side an edge on which the carriers slide, they are prepared to be subjected to the intense heating produced by the flames which are formed at O, *a*, and which traverse the kiln from the bottom to the top by passing through the openings formed immediately above. The flames then pass into the upper flue *c*, which extends along the kiln, dampers *d* being provided for the purpose of regulating the egress of the flames. Each vertical row of passages thus becomes a kiln into which the products to be baked or heated pass, and the flame of which is regulated at will at both its admission and outlet. The time for traversing the passage is varied according to the nature of the materials to be baked. As soon as the zone of flames is traversed, it is required that the cooling should commence, which is only possible on the condition of being able to carry off the caloric radiated from the burnt products. This caloric is transmitted to the partitions and to the soles; and in order to utilize the heat thus absorbed, the latter portion of the partitions is made hollow. The iron flooring carrying the lower sole of the kiln admits of passing beneath, in order to attend to the dampers *b*, Fig. 4824, and of the air being conducted to the heat regenerator. The iron flooring is so arranged as to admit of air readily passing into the partitions. The perforated soles also cause a draught, which, in conjunction with the absorption by means of the current of air in the partitions of the caloric radiated, admits of the successive cooling of the burnt products.

At the end of the upper passage, which receives the flames proceeding from the ovens, the flames are separated into two, and descend through vertical flues. On arriving at the bottom of

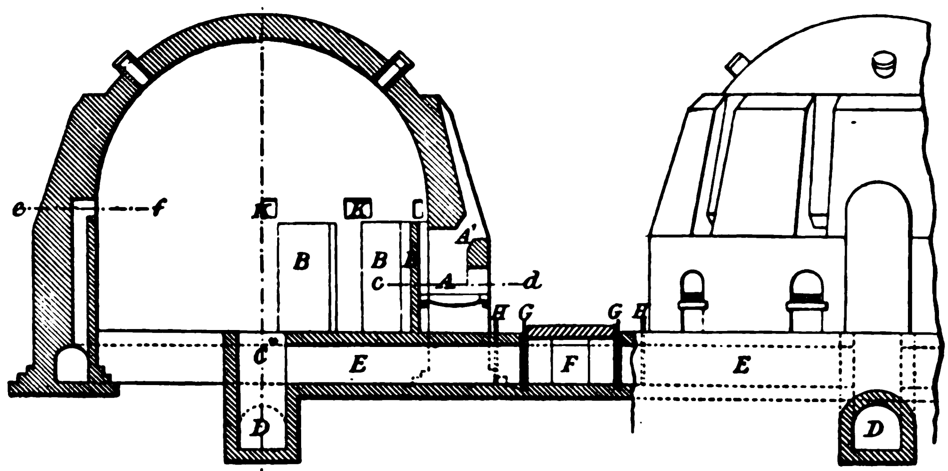
the kiln, the flames circulate in two passages at the side of those for the carbonic oxide. These passages are formed in two tiers, in which the circulation is in the downward direction; but through the tubes the air passes upwards to this kiln with the greatest simplicity.

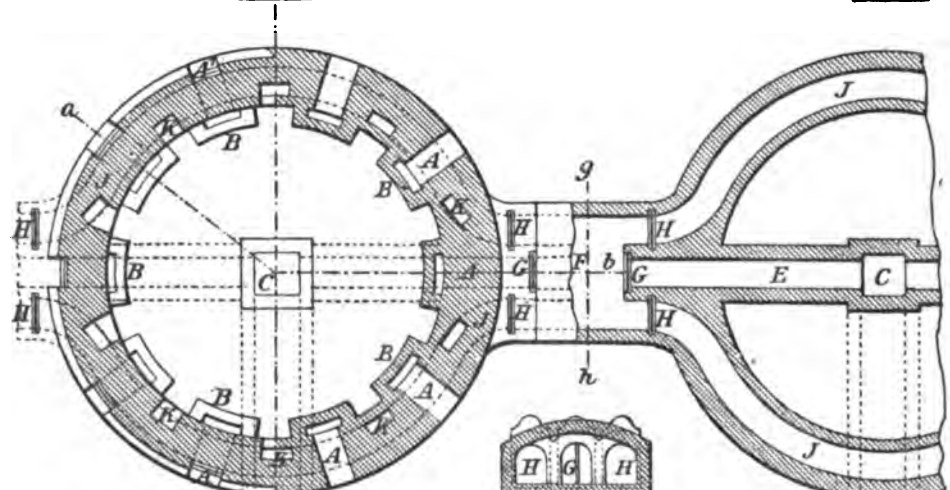
Fig. 4825 is a vertical section, taken at line *a b* of Fig. 4827, of one of A. Batchelar's kilns; Fig. 4826 an elevation of a similar kiln; Fig. 4827 a sectional plan, one half being taken at *c d* through furnaces in Fig. 4825, and the other half at *e f* in the same figure; Fig. 4828 a sectional plan through the horizontal heat flues.

Batchelar usually employs a kiln circular in plan, and having a domed roof, as shown in the drawing; but kilns of other forms may be constructed in accordance with his arrangement.

A A are furnaces constructed in the thickness of the wall with fire-bars in the ordinary manner, each furnace being fed with fuel through the opening A¹, which is closed when the furnace is in

4825. 4826.





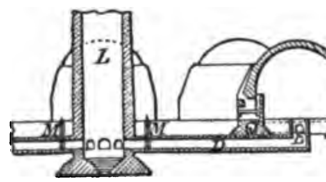
4827. 4828.

operation. The number of furnaces may be varied, according to the size of kiln and quality of material to be operated upon. In the example shown ten are employed. Inside the kiln, and opposite to each furnace, are built short walls B B, forming a casing or pocket round the end of each fire-place, which directs the heat and flame upwards towards the upper part of the goods stacked in the kiln. In the floor of the kiln there is an opening C leading into the main flue D, which conducts the heated products of combustion direct to the chimney, when in the course of burning it is necessary to so dispose of them. There are also formed beneath the floor of the kiln heat flues E E, which each open at one end into the passage C, and at the other end into chambers F, constructed in the space between two adjacent kilns; dampers G G are adapted to close the ends of the heat flues when required. Flues J are constructed in the wall of the kiln near the

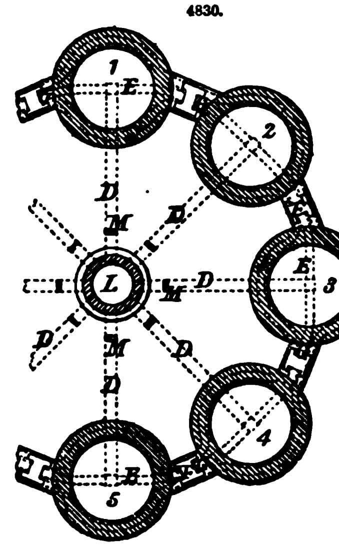
bottom. Short vertical heat flues K K are also formed in the wall of the kiln; their lower ends communicate with the flues J, and their upper ends open into the kiln, Figs. 4825 and 4827. The flues J pass half round each kiln, and open at each end into the chambers F by the side of the flues E, the ends of flues J being also closed by dampers H H when required.

Figs. 4829, 830, show the arrangement of these kilns in a series for working them in rotation, so as to utilize the waste heat passing from the kiln in active operation to the purpose of drying

4829.



4830.



green or unburnt goods stacked in another kiln, in order to prepare them for the final burning. Numbers 1 to 5 represent a series of the above-described kilns grouped round a central chimney L. Main flues D D lead from the centre of each kiln to the chimney shaft, dampers M M being fitted to each flue to open or close communication between the kilns and chimney, as may be desired.

The method of working these kilns in a series is as follows:—Supposing the fires to be lighted in kiln No. 3, Fig. 4830, the dampers H H at end of heat flues J are kept closed, the damper M^3 in the main flue of that kiln leading to the chimney is opened until the fires are well burnt up, when the damper M^3 may be partly closed, and the dampers H^4 H^4 leading from chamber F into heat flues J J of kiln No. 4, in which green goods are stacked, are partly opened, the damper M^4 in main flue leading to chimney of No. 4 kiln being also opened, the damper G^4 being meanwhile kept closed, and G^3 open. By these means one portion of the heated gases generated in kiln No. 3 passes direct to the chimney, and the other portion by the heat flue E into the heat flues J J, and so by flues K K into kiln No. 4, thence through and amongst the green goods, and finally escapes by the main flue D of No. 4 kiln into the chimney. By properly adjusting the dampers in the flues as indicated, the amount of waste gases passed from the kiln in operation to the next may be so regulated as to ensure a proper draught for maintaining the combustion of the fuel at all stages of the operation, and by gradually closing the damper of the kiln in operation leading direct to the chimney, and opening that leading to the next kiln, the whole of the waste gases may be passed through the latter towards the completion of the firing operation of the first kiln; and by that time the goods in the second kiln will have attained a very high temperature. As soon as kiln No. 3 is burnt off, the damper G^3, leading to kiln No. 4, may be closed, as also partially the damper M^3 in main flue, and the kiln left to cool gradually. Kiln No. 5, the next in order, containing green bricks, will be gradually brought into communication with kiln No. 4 by means of the dampers, when its fires are lighted in the same manner as described for Nos. 3 and 4. Kiln No. 2 in the series having been burnt off previously to No. 3, will have been cooling while the latter was burning, and No. 1 having been previously cooled, the fired goods will have been discharged from it, and green goods recharged into it. Whilst No. 3 kiln has been burning, No. 7 has also been burning, and Nos. 5, 6, and 8 have held the same position in relation to it that Nos. 1, 2, and 4 have been described as holding to No. 3. If desired, dampers may be so arranged in the passages C of each kiln, as seen in dotted lines at *, Fig. 4825, that the heat flues E may be shut off entirely from any number of kilns; by this means a communication may be opened between a kiln which is being cooled and another in the series not immediately adjacent containing green goods.

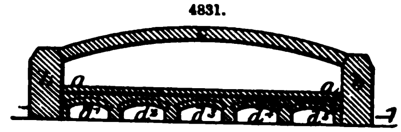
The usual consumption of coal a thousand of ordinary bricks varies in these kilns from 3 to 4 cwt., according to the kind of clay used. Each kiln is usually of sufficient capacity to contain from 20,000 to 30,000 bricks, and the time occupied in burning off a charge after it has been thoroughly dried by the waste heated gases from the kiln last burnt ranges from thirty-six to forty-eight hours. An ordinary Staffordshire kiln, merely heated by the furnaces, and without any provision for the employment of the waste heat, will consume from 6 to 7½ cwt. of coals a thousand. In the burning of bricks made from refractory fire-clay, these kilns have effected a saving of 4 to 5 cwt. of coal a thousand, and a reduction in the time of burning from ninety-six to forty hours, the goods being of excellent quality and the waste very small.

In burning lime the economy of the kilns is as marked as in burning clay objects, the consumption of coal a yard of lime burnt in them being 1½ to 2 cwt., as against 3½ to 4 cwt. a yard in the ordinary lime-kiln.

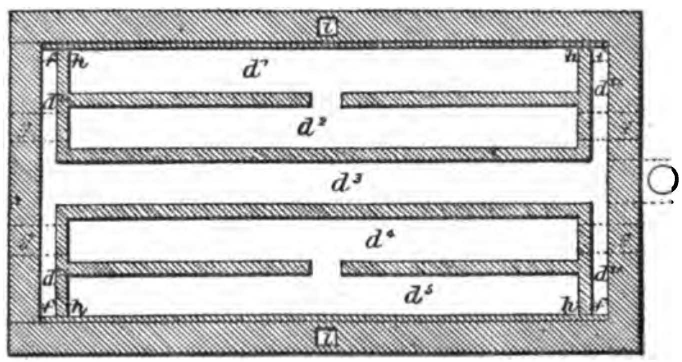
Fig. 4831 is a transverse section of John Crossley's *annealing* kiln. Fig. 4832, a horizontal section taken on line 1 1, Fig. 4831. *a a*, the bed of the kiln; *b b*, its side walls; *c*, the covering arch over it; d^1 to d^5, longitudinal flues beneath the bed. Extending across the front of the kiln is the door for placing and removing the sheets of glass. At the back of the kiln gas fuel is

admitted past a regulating valve e into the centre flue d^3, and passes from this flue by the branch flues $d^{3\times}$ to the openings ff, in the bed of the kiln at its four corners. Each of the openings f is fitted with a slide by which the width of the opening can be regulated and the quantity of gas admitted by it adjusted; $g\,g$ are underground passages by which air can enter the flues d^2 and d^4; it passes from these into the flues d^1 and d^5, and then ascends into the body of the kiln by the four openings $h\,h$, in the bed in close proximity to the openings f by which the gas is admitted; the heated gas thus meeting the heated air is burnt within the kiln and the products of combustion pass away

4831.



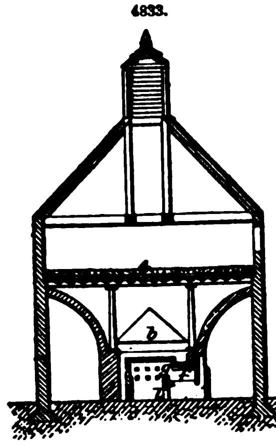
4832.



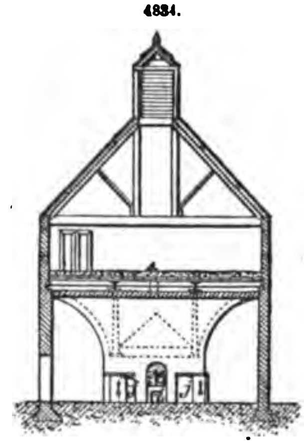
by two side openings regulated by dampers into the flues $i\,i$, which lead down into an underground passage running beneath the series of kilns to a chimney. Whilst the glass is being placed in the kiln the openings f and h at the front of the bed are covered with iron gratings, which are afterwards removed. When the kiln is cooling, air is allowed to enter all the flues beneath the bed, and it passes over the bed to the chimney, the rapidity of cooling being controlled by the dampers in connection with the chimney flues i, or the air may be allowed to circulate through the flues without passing over the bed of the kiln.

Malt-kilns.—Considerable difference of opinion exists amongst maltsters as to the forms of malt-kilns, and the most suitable material for kiln floors. A good ordinary malt-kiln is shown in Figs. 4833, 4834. The furnace f is placed in the centre of the kiln, and is in communication with

4833.



4834.

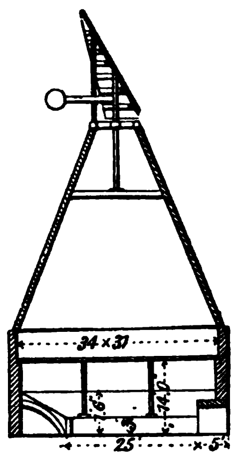


the enclosure or lamp g, in the sides and crown of which there are openings for flames and heated air to pass through. The lamp can be cleaned out through the opening i communicating with the ash-pit, this opening serving also to admit a portion of the air which it is necessary to apply to the kiln in addition to that which passes through the fire. The opening i is, however, of such size that it will admit less than the minimum quantity thus needed, the remainder being supplied through the openings or ventilators J J, which are fitted with sliding dampers, so that the quantity of air allowed to pass through them is under complete control. The furnace is enclosed by walls arched over to the sides of the kiln, and above the lamp is placed the pyramidal distributing plate b. This not only serves to equalize the temperature of the various parts of the kiln floor,

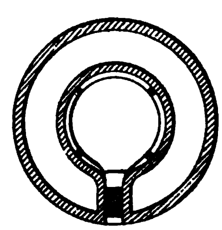
but also throws off any coomings or roots which may fall through, and which would otherwise fall upon the lamp and furnace, where they would accumulate and take fire, giving the malt on the kiln a singed taste. The floor of the kiln is formed of cast-iron plates,—the 18-in. square pattern with oblong holes. The pillars, plate-bars, and girders supporting the floor of the kiln are also of cast iron.

Fig. 4835 is a form of kiln which is extensively used. In this kiln the fire is at one side, and the crown of the arch over it is about 3 ft. 6 in. above the highest part of the fire-grate, so that there is ample space for the passage of air. The quantity of air admitted is regulated by a cast-iron sliding plate fitted to the outside opening of the furnace. This plate is not shown in the engraving. In the case of the kiln, Fig. 4835, the fire-grate is about 3 ft. 6 in. long, 2 ft. in width,

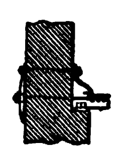
4835.



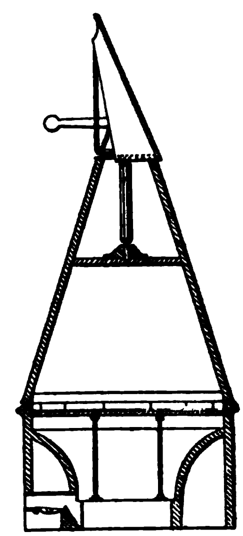
4836.



4838.



4837.



and the bars, the upper sides of which are about 16 in. above the ground level at their highest ends, are laid with a slope of about 4 in. in their length. The heated air from the fire is diffused over the kiln by a disperser plate 15 ft. long and 12 ft. wide, placed 7 ft. 6 in. above the ground level, as indicated by the dotted line. This kiln is for pale malt, and in conjunction with another kiln of the same size, will dry the produce of a 90-quarter malt-house.

Figs. 4836, 4837, are another variety of the circular malt-kiln, as erected by Byran, Corcoran, and Co., of London. It will be seen that in this kiln the lower part as well as the dome is circular, and this form, combined with the arrangements of the fire and the arches enclosing the kiln pit, causes the heated air to pass very equally through all parts of the floor.

In this kiln the dome is of brickwork instead of wood, as usual, being formed by carrying up the sides of the kiln and gradually closing them inwards. In a kiln of this kind for drying off 25 quarters at one time the principal dimensions will be;—

	ft.	in.
Diameter of floor	25	0
" opening at top of dome	6	0
" kiln pit	12	6
Height of floor above grate level	12	6
" dome	38	0
" cowl	19	0

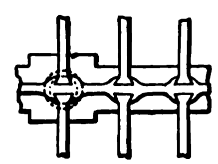
The floor of a malt-kiln should have an area of not less than 20 sq. ft. for every quarter of malt to be dried on it at one time; but this area, which would require the grain to be spread upon the floor to a depth of a little over 10 in., will have to be considerably increased in many instances where a good draught is not available.

Formerly floors used to be largely made of hair-cloth; but this material is now out of date. At present the floors most in use are made of tiles. The tiles for kiln floors are generally cored out or recessed on the under side, so that the small perforations which pass through the tiles extend through a slight thickness of material only. The coring out also greatly reduces the weight of the tiles. The perforations for the passage of air should be clearly formed and perfectly free from any burrs, which would cut the grain. In Scotch kilns the floors are generally made of perforated cast-iron plates, usually 18 in. square, and having the stobs cast in them. The plates are carried by cast-iron bearers having dovetail-shaped ends, which fit into jaws cast on the sides of the main girders, as in Fig. 4839. The main girders are supported by columns at intermediate points, Figs. 4840, 4841. These plates have the advantage of being less brittle than the tiles, whilst, like them, they absorb a considerable quantity of heat, and cause the drying of the malt laid on them to be, to a great extent, completed by a radiant heat only.

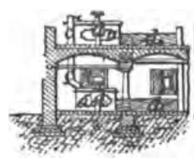
Tile floors are very safe floors, as from the limited area of their perforations they render it

almost impossible to merely air-dry the malt; but on the other hand they retain so much heat that if the fire is allowed to get too high, there is a danger of the malt becoming scorched. Another

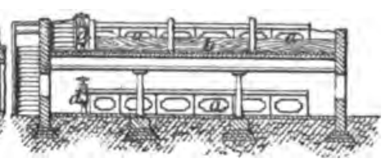
4839.



4840.



4841.



material which has been largely used for kiln floors is wove wire, and, if properly applied, floors made of this material are very durable. To fix the wove-wire floo , the edges of the wire are laced or sewn to straining bars, and these bars are taken hold of by hooked bolts which pass through the wall of the kiln, as in Fig. 4838, each bolt being provided with a large washer-plate bearing on four courses of bricks. The straining bars are covered by a cast-iron skirting plate. The plate or wire is supported by round bars placed at 2½ in. pitch, these bars resting in half-round holes formed in the upper edges of the longitudinal beams, which are of wrought iron 4 in. deep by 1 in. thick. These beams are carried partly by the walls of the kiln and partly by cast-iron cross-girders, in their turn supported at intermediate points by columns. The use of the round bars immediately beneath the wove wire leaves almost the whole area of the latter clear for the passage of air, and there is less chance of dust or dirt lodging on the round bars than there would be on bars flat on their upper edges. Wire floors require to be well protected from rust, and probably the best method of preserving them is to cover them, when not in use, to a depth of about 8 in., with oat husks or with dry straw to a depth of about 18 in. A peculiar kind of wire gauze for kiln floors has recently been introduced by Morton and Wilson, of London. This gauze, after being wove, is passed between smooth steel rollers, which have the effect of indenting the intersecting wires into each other, and thus producing a perfectly level surface, on which the shovelling and turning of the malt can be very readily performed.

Wire gauze can sometimes be advantageously employed for equalizing the draught at different portions of a kiln. For this purpose sheets of the gauze must be suspended beneath the floor at those points at which the draught is strongest, the size of the gauze being regulated according to the amount of checking effect which it is desired to produce. Punched wrought-iron plates are sometimes used as a substitute for wove wire for kiln floors, and on the Continent large quantities of such plates are employed.

In considering the qualifications of different kinds of kiln floors it must be borne in mind that the advantages or disadvantages of any particular kind of floor may be materially modified by the nature of the draught available, and the means provided for regulating it. If the ventilation of a kiln is under thorough control, good malt may be produced on any of the floors we have mentioned. The opening at the top of a malt-kiln is provided either with a revolving cowl, as in the case of the kiln, Fig. 4835, or with a short shaft or cupola, fitted with louvre boards, as in Figs. 4833, 4834. This latter plan is the cheaper of the two; but the cowl, if properly constructed, is probably the most effective in excluding down draughts of cold air. If, however, the cowl is not made so as to move freely it may cause the very effects that it is used to prevent. Cowls are generally made of wood; but a great many copper cowls have been erected, and from their lightness and cheapness they are to be recommended. Cowls may also be made of galvanized iron or of zinc, but these materials are far less durable than copper.

The opening at the top of the kiln should be of sufficient size to carry off freely the moisture arising from the malt, and the area of opening necessary to do this will depend to some extent upon the draught available. To improve this draught as much as possible all apertures opening into the dome should be well fitted, so that they may be closed perfectly, and the dome itself should be of good height. Generally, with a fair draught, an opening equal to from one-thirtieth to one-thirty-fifth of the area of the kiln floor will be found sufficient; but Corcoran and Co. give a much larger opening, that of the kiln, Fig. 4835 being about one-eighteenth of the area of the floor.

The fuel used in a malt-kiln should be free from sulphur, as although the sulphurous acid generated by the combustion of such sulphur may, by its bleaching action, sometimes improve the appearance of the malt, yet it decidedly injures its quality, and lessens its value to the brewer. Well-made coke and good anthracite both make excellent fuel for malt-kilns; a ton of the former dried off in a well-constructed kiln about 50 quarters, and a ton of the latter, 55 quarters of malt.

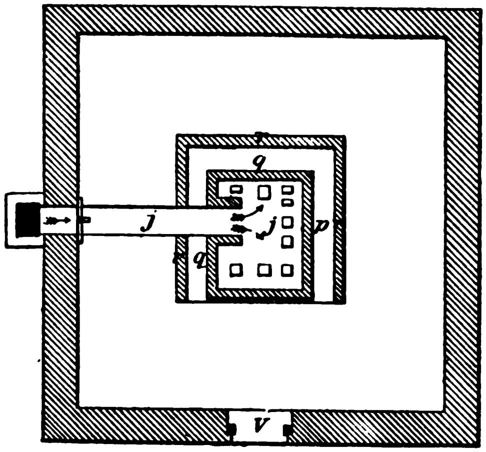
As we have stated, the heat at which malt should be dried depends upon the character of the malt; the lower the temperature of the heated air the malt is dried with, the plumper and more productive is the malt, but for fulness of flavour a higher temperature is required. The important point in properly kiln-drying malt is to pass a volume of heated air through the malt to convey away the vapour through the cowl or cupola at the top of the kiln. This is well effected by Thos. Bright's kiln and hot-air apparatus, Figs. 4842 to 4846, which prevents cold and unequal currents, and supplies an unlimited quantity of pure heated air.

Fig. 4842, a plan of cold-air flues under the chambers. Fig. 4843, a plan showing grate-bars and smoke-pipes. Fig. 4844, sectional elevation, with side wall and slope removed. Fig. 4845, cross-sectional elevation. Fig. 4846, transverse sectional elevation.

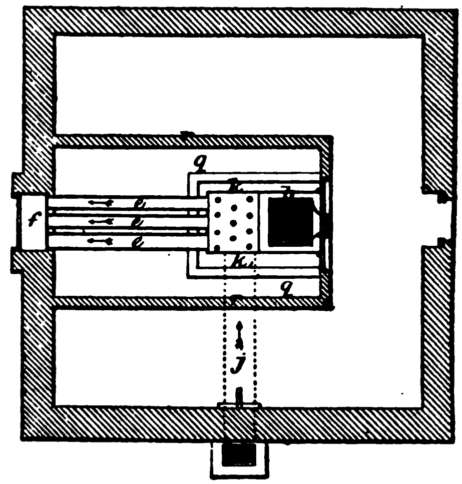
The heat in the kiln pit, until the steam is well off, should not exceed 100. If a high heat be

applied when the malt is moist, it impairs the flavour and soluble properties of the malt, and that portion of the gluten unconverted becomes so fixed as to render the otherwise friable matter, hard and difficult of solution in the mash tub. Bright's kiln prevents overheating by being supplied

4842.



4843.



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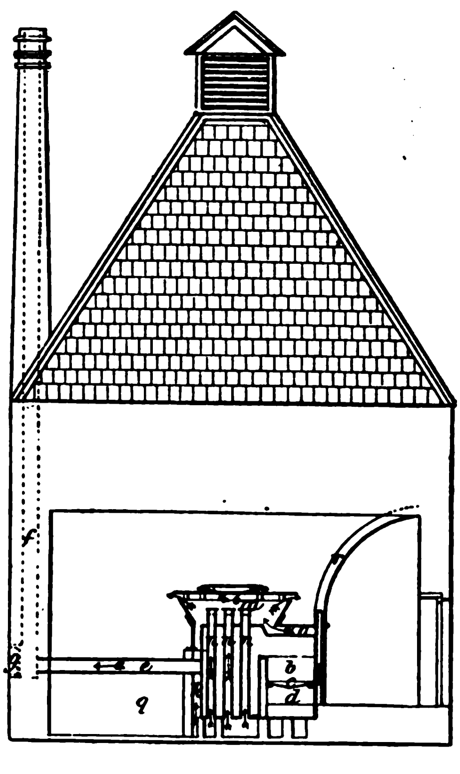
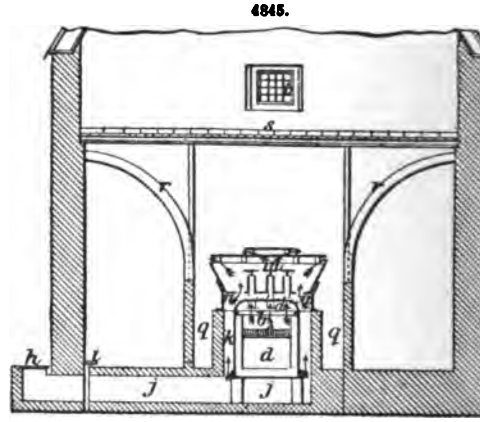
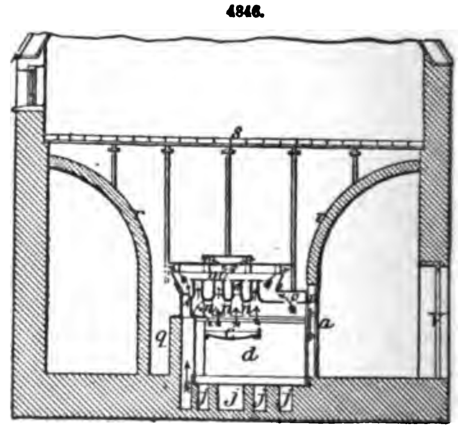


4845.



4846.



with air heated to the temperature required, which can be regulated at the will of the maltster. Pale malt requires but once turning on this kiln, and the difficulty of drying it is considerably decreased.

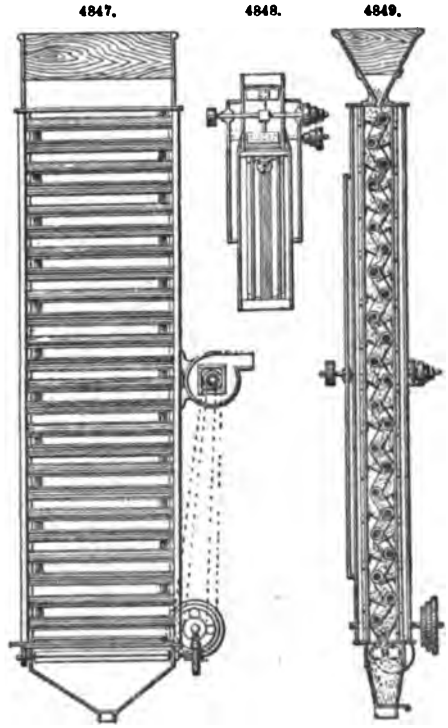
The kiln is not affected by rough weather; and will always ensure a regular and well-dried sample of malt or hops.

a, doors on fire-place; *b*, fire-place; *c*, grate bars; *d*, ash-pit; *e*, pipes or smoke flues for bituminous coal; *f*, chimney stack; *g*, doors to open for cleaning smoke pipes or flues; *h*, grating on cold-air flues; *i*, damper on cold-air flues, to regulate the air admitted into the flue; *j*, cold-air flue to chambers; *k*, chamber on the sides and back of fire-place; *l*, doors on openings into chamber round fire-place; *m*, chamber over the fire-place for generating hot air which passes through the openings in and under the covers in the direction shown by the arrows to the space under the kiln floor; *n*, connecting pipes from chamber *k* at the sides and back of fire-place to the chamber *m* over the fire-place; *o*, opening over fire-doors to admit cold air into chamber *m*; *p*, slide to regulate the air admitted to chamber *m*; *q*, square for malt dust; *r*, slopes under kiln floor; *s*, perforated kiln floor; *t*, window; *u*, cupola on top of kiln for the discharge of the vapour arising from the goods drying; *v*, doors into bottom of kiln.

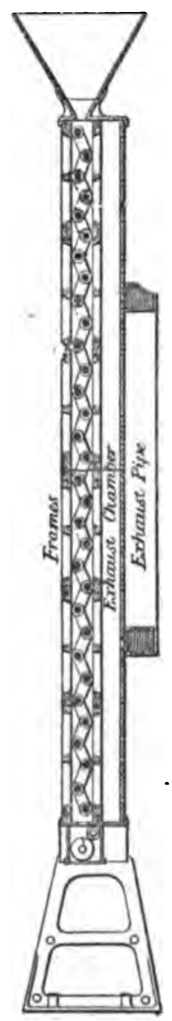
Figs. 4847 to 4849 are of Don, Smith, and Horsfield's kiln, for drying grain seeds and similar products.

The peculiar feature in this kiln consists in the employment of a number of steam-pipes fixed one above another, round which the grain is constantly moving in a thin layer. It is by this means dried rapidly and with evenness; and the possibility of burning or scorching, which on the old system of drying could scarcely be avoided, is prevented.

4847. 4848. 4849.



4850.



The action of this kiln is as follows;—The wheat or other grain passes into a hopper at the top, and gradually works its way round the pipes in its descent, being kept in contact with the steam-pipes by a ceiling of perforated zinc on each side, at the same time a current of air is drawn through and among the grain while in motion by a powerful exhaust-fan, fixed to the apparatus which carries away all the moisture as fast as it is evaporated from the heated grain, and thus greatly facilitates the drying and improves the grain; so that by the time it arrives at the bottom where it is delivered into sacks or elevators the grain is cool and dry, and ready for immediate use, or to retain in store.

This kiln is well adapted to the drying of Egyptian and Black Sea wheat or other grain that has been washed for the purpose of freeing it from clods of earth, and impurities, and for sweetening and mollifying grain injured by salt water, heated in the hold of the vessel during its passage; or found to be too dry and flinty for grinding purposes.

Don's kiln is a most valuable machine when English or other grain has been injured by bad harvesting; for by being passed a few times through this apparatus, any damp, soft, or musty wheat can be dried and greatly improved by the exhausted air alone.

Fig. 4850 is a view of one of Don's kilns, erected on metal standards by the side of a wall. The pipes were 1¼-in. steam-tubes placed zigzag, and the upright sides of the kiln composed of a series of frames, the inside of the frames next the tube space being covered with wire cloth; perforated sheet zinc or copper pierced sufficiently with small holes would do as well. The object of this arrangement is to let the air pass through, but to prevent the grain from passing. In the lower box is a grooved roller which regulates the speed as it revolves faster or slower; it also regulates the time of drying the grain by retarding or quickening its passage through the kiln. The lower box contains in addition a worm or screw to convey the grain for delivery at one end of the box after it has passed the regulating roller. The exhaust-chamber is in this case placed on one side of the kiln, the other side being open to allow the air to pass through and cool the grain, and convey the steam evolved from it. This steam is drawn into the outer exhaust-spout, which is connected to the eye of the exhaust-fan, and from the exhaust-spout to the outside of the building.

Fig. 4851 is an elevation of a pair of the kilns erected for drying peas and maize; the fan is here shown as driving the air and moisture from the kilns. There are two elevators, one to lift the

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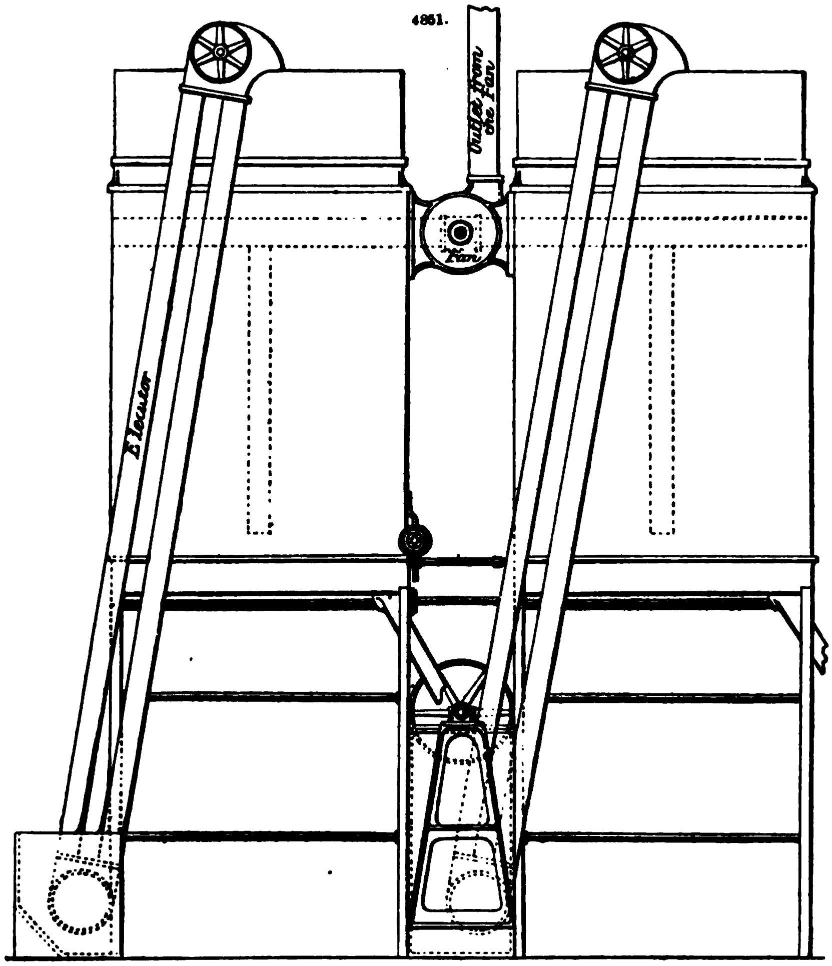


grain from the floor to the top of the first kiln, the other to raise and deliver it to the second kiln. The articles thus pass through both kilns; this is necessary, as peas require to be partially baked. The pair of kilns from which our drawing was taken dry 10 quarters of peas in an hour.

KING-POST. Fr., *Poinçon*; Ger., *Hangesäule*.

See Construction, p. 1030. Joints.

KNIFE-EDGE. Fr., *Couteau*; Ger., *Schneide*.

See Balance.

KNITTING MACHINE. Fr., *Machine à tricoter*; Ger., *Strickmaschiene*.

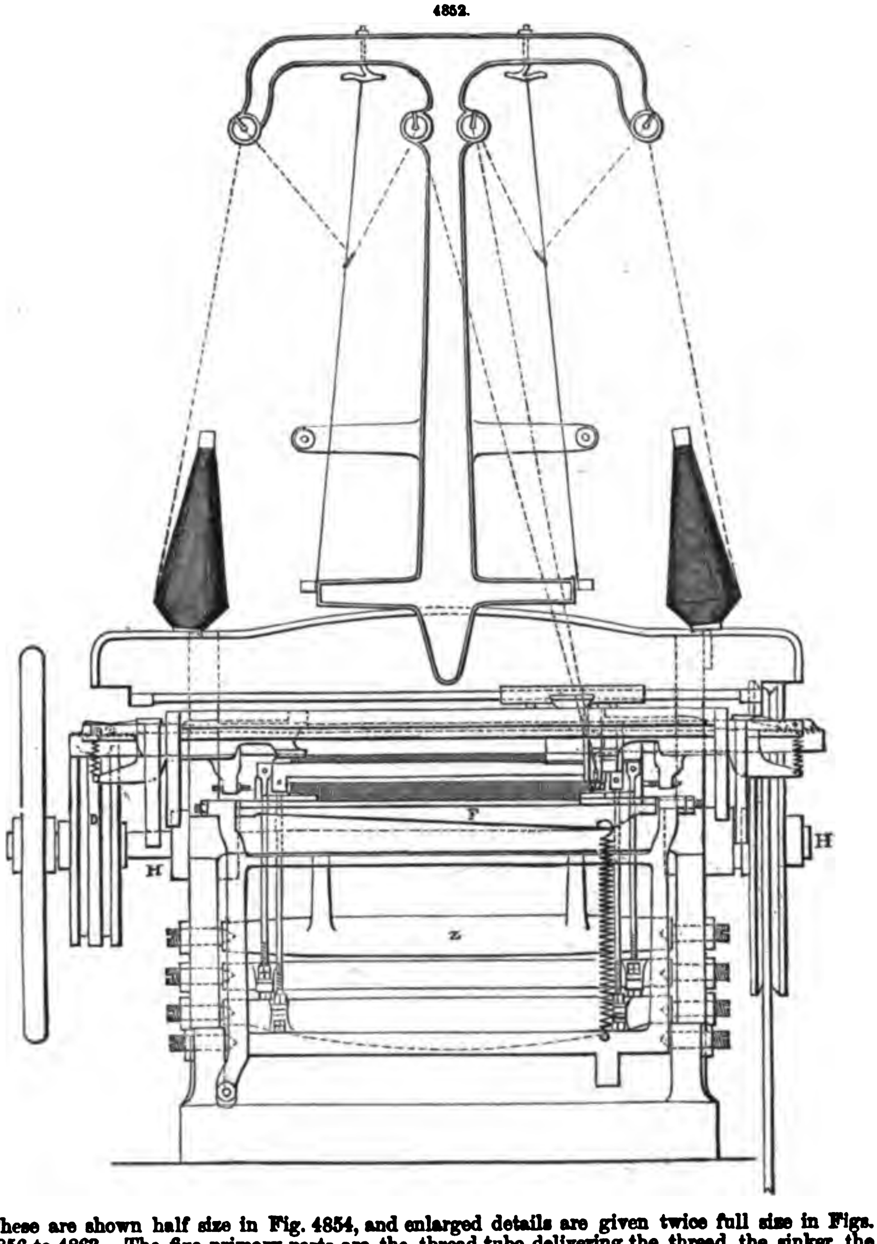
The nature of the structure of knitted web is shown in the magnified diagrams, Figs. 4866, 4867, which represent a back view and side section of knitted web; it will be seen that one thread here does duty for both warp and weft, and is itself woven direct from the bobbin into a web consisting of rows of loops, the loops in each row being drawn through those in the row immediately preceding. In hand knitting this action is performed either by the ordinary knitting pins or by the crochet hook, and in both cases each loop is separated and individually made complete; or, as in the case of the old framework-knitter's frame, each row of loops is made by a hand apparatus, and then drawn through the previous row at one operation.

In most knitted articles it is necessary that, during the process of making the web from the thread or yarn, it should also be shaped at the same time that it is made. This is one great peculiarity of the hosiery manufactured, that shaped wearing apparel, comprising the numerous descriptions of under-clothing, is produced direct from the yarn at one operation of the machine, and without the intervention of the tailor or milliner; and the weaver of calico, cloth, or other such fabrics, will hardly realize at once the amount of detail which this peculiarity involves in the manufacture of hosiery, to suit all the different shapes and qualities required, entailing as it does the necessity that the machines employed shall be easily adapted to make articles of very

good variety of shapes, thickness, and degrees of elasticity. The framework-knitter's old hand-frame, which has for so many years been almost the only apparatus commercially employed in manufacturing knitted wearing apparel, though now doomed to the same fate as many other clever contrivances of former years, is even yet in the Midland district in England the means of producing the larger part of the hosiery made.

The self-acting machine for knitting hosiery by power, invented by Arthur Paget, and described by him before the Inst. M. E. in 1870, is shown in general elevation and section in Figs. 4852, 4853, and its construction and action will be better understood by confining the attention at first to the five primary parts which actually manipulate the thread in knitting it into web.

4852.

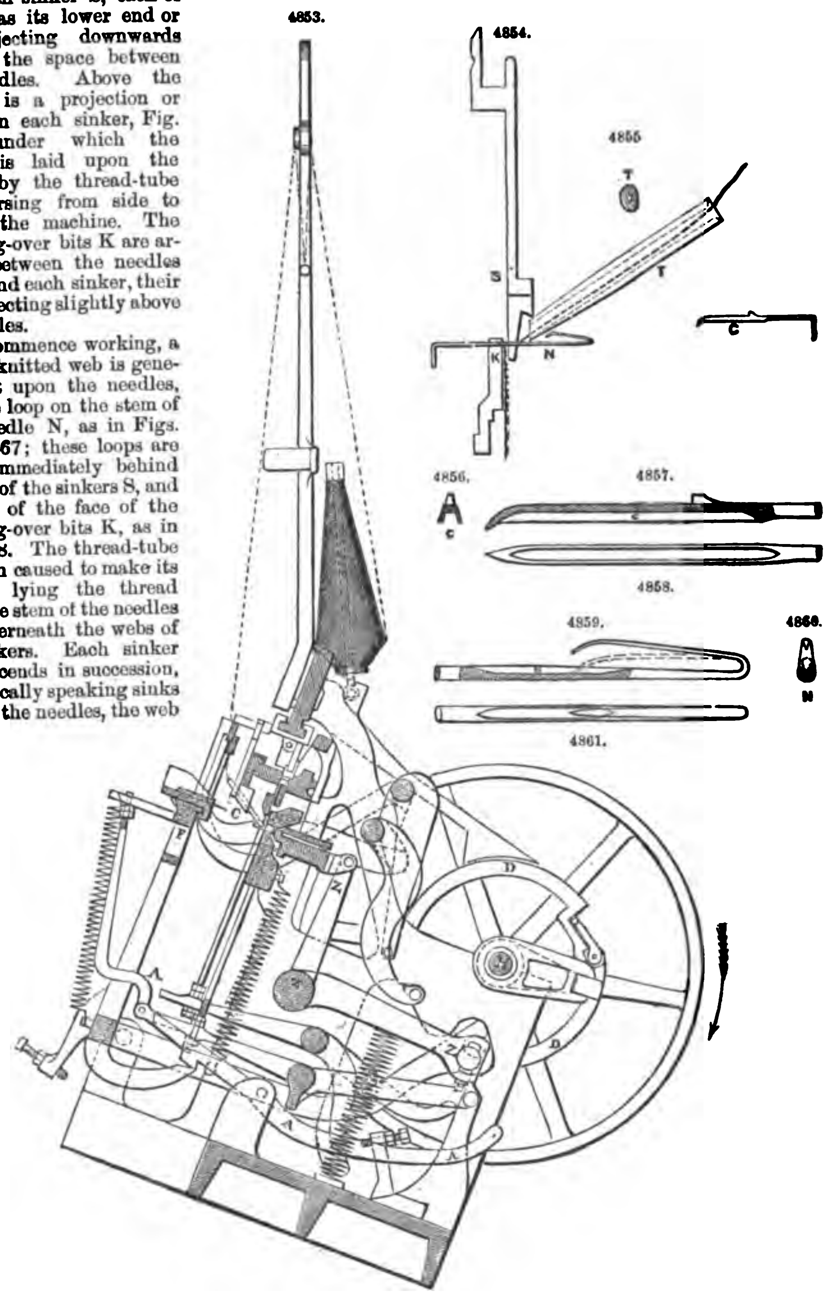


These are shown half size in Fig. 4854, and enlarged details are given twice full size in Figs. 4856 to 4863. The five primary parts are the thread-tube delivering the thread, the sinker, the needle, the knocking-over bit, and the coverer. The action will first be explained of these five primary parts which manipulate the thread, and then of the secondary parts which effect the movements of the primary parts.

Knitting.—In the making of the web, as contradistinguished from narrowing or shaping it, the

four first-mentioned of the above primary parts are employed, the cover being used only when narrowing; and the successive stages in the process of making the web are shown in Figs. 4868 and 4875. The needles are all arranged side by side in a row as wide as the greatest width of the article to be knitted, as seen at N in Figs. 4865, 4866, and above and between the needles is a projection or web upon each sinker S, each of which has its lower end or tail projecting downwards through the space between the needles. Above the needles is a projection or web upon each sinker, Fig. 4865, under which the thread is laid upon the needles by the thread-tube T traversing from side to side in the machine. The knocking-over bits K are arranged between the needles one behind each sinker, their tops projecting slightly above the needles.

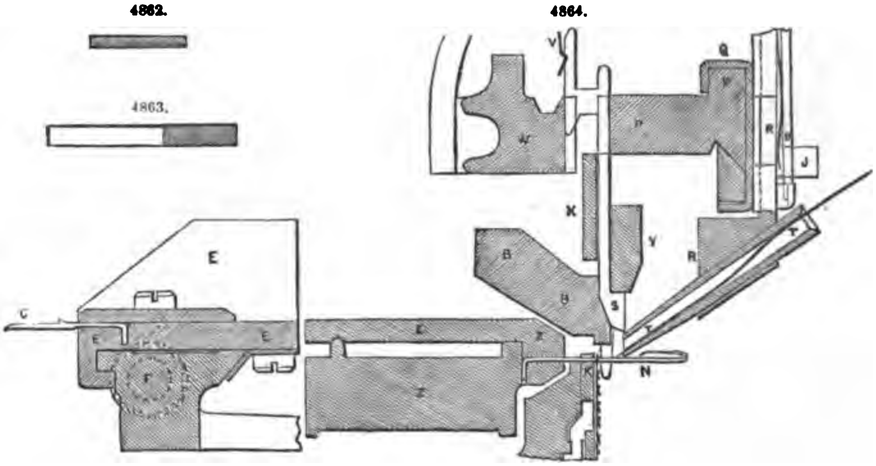
To commence working, a piece of knitted web is generally put upon the needles, with one loop on the stem of each needle N, as in Figs. 4866, 4867; these loops are placed immediately behind the tails of the sinkers S, and in front of the face of the knocking-over bits K, as in Fig. 4868. The thread-tube T is then caused to make its traverse, lying the thread across the stem of the needles and underneath the webs of the sinkers. Each sinker then descends in succession, or technically speaking sinks between the needles, the web carrying down with it a loop of the thread; in this way a series or row of loops is formed, hanging on the stems of the needles, as in Fig. 4869. The curve of the sinker incline A, Fig. 4865, which depresses the sinkers in succession as it traverses across the machine, is made of such a form that each sinker has fully completed its descent or sunk its loop, before the web of the next one comes down upon the thread. If this were not done, the thread would have to be drawn up by the one sinker under the next one, while the latter was pressing on the thread; and as most hosiery



threads are only slightly twisted, and consequently of very little strength, the thread would be injured by such a tension upon it. When the thread-tube T arrives at the end of its traverse, that is, when the required width of needles has been passed over, it descends and carries the thread down between two of the needles, as in Fig. 4869, thus forming the loop of the last or selvedge needle without the aid of the sinker. The whole row of needles then retire or are drawn backwards, as in Fig. 4870; and the ends of the hooks, technically called the beards of the needles, pass over and enclose the loops just formed by the sinkers.

The presser-bar B, Figs. 4864 and 4871, now descends; and being made with grooves in its face

4862. 4863. 4864.



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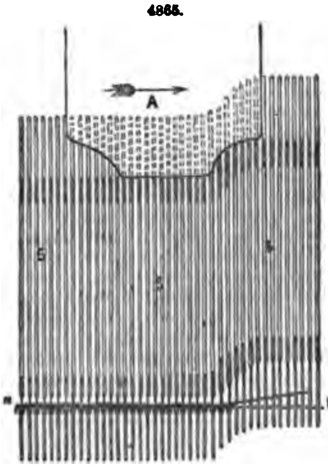
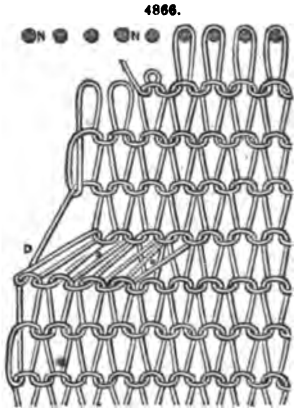


4866.



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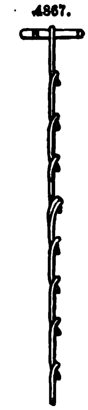
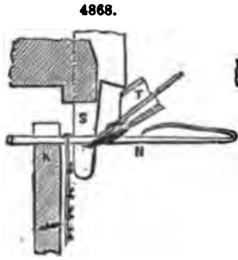


4868.



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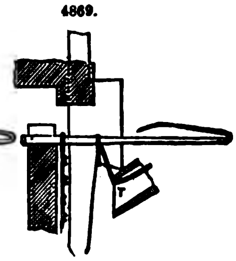

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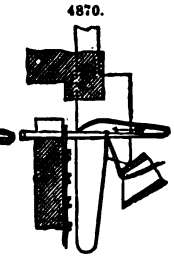
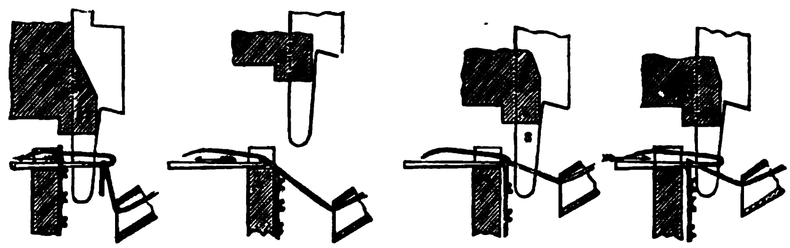


4871.

through which the sinkers slide, the walls of these grooves press the points of the beards of the needles into the grooves in their stems, as seen in Fig. 4871, and dotted in Fig. 4859. The needles then retire still farther, the new loops being still round the stems and under the beards of the needles, while the old loops now slide over the beards, as in Fig. 4872, and the presser-bar B is raised again as soon as the points of the beards have fairly entered the old loops on the needles,

Fig. 4872. The needles, still continuing to retire, draw the new loops which are under the beards up to the old ones which are over the beards, and then draw the new loops through the old ones, the latter being held by the knocking-over bits K, as in Fig. 4873. When the needles next advance, the old loops draw down below the heads of the needles, as in Fig. 4874; this process is called knocking over the loops, and to ensure its being thoroughly done and all the loops well bevelled, in length, the needles are made to retire a second time, and thus draw the loops again tight against the face of the knocking-over bits. The needles then advance, and the sinkers S descend, as in Fig. 4874, so that the tails of the sinkers keep the loops behind them, while the needles continue to advance and their stems slide forward through the new loops, as in Fig. 4875, until they have reached again their former position, shown in Fig 4868. The thread-

4872. 4873. 4874. 4875.



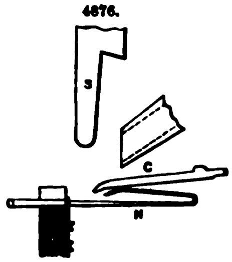
tube T now descends between the same two needles between which it previously descended; and all the parts assume the position they were in before the commencement of the knitting this first row of loops, as in Fig. 4868, with the exception that the thread-tube is now at the other side of the machine. The same process is then repeated, the thread-tube now lying the thread across the needles from left to right, instead of from right to left as before; and thus the knitted web is increased successively by adding a row of loops, called a course, alternately from left to right and from right to left, one course being added for each revolution of the cam-shaft of the machine.

Narrowing.—For narrowing the knitted web in order to shape or fashion it, the simplest method would seem to be merely to stop the traverse of the thread-tube one, two, or more needles earlier than before, and so make the web narrower on one or both sides. But if this were all that was done, the loops on the needles so left beyond the traverse of the thread-tube would in the next course be pushed off the needles and dropped; and, as will be seen from the diagram, Fig. 4866, a dropped loop or stitch in knitted web runs down as it is termed, and produces a defect or kind of elongated hole commonly called a ladder. To avoid this defect it is necessary to secure the loops which would thus be pushed off the needles and dropped; and the method employed to effect this is identical, as far as the construction of the web is concerned, with that used for many years by the framework knitters. This method consists in narrowing the web at certain intervals by two needles at a time, the intervals or number of courses between each narrowing being regulated so as to produce an approximation to the curve desired, as, for instance, in the leg of a stocking, so as to fit correctly. The approximation is used, because if the web knitted were rigid and inelastic the shape produced would really be narrowed by a series of sudden steps instead of being a suitable curve; but as the knitted web is thoroughly elastic, the steps are not perceptible, and the result is a well-shaped stocking or other article. The essential principle of the narrowing is that the two loops to be narrowed are removed from two needles at the edge of the web, and are transferred to the two needles next to them and nearer to the centre of the machine. Thus these two needles have each two loops upon them, and one of the loops in the next row of knitting is then drawn through each of these pairs of loops, exactly as before described in making web; by this means the loops, which would otherwise have run down, are held secure. But as this pair of double loops produce a slight thickening and distortion of the web wherever they occur, and as it is considered a point of great importance to avoid even the slightest irregularity of the selvedge, it is usual to transfer four loops instead of only two, and to move them all four a distance of two needles sideways, as before described; thus the two loops nearest the selvedge are left single and perfect, and the thickening is produced in the next two loops, as shown at D in Fig. 4866. Instead of moving four loops, any other number might be moved; and instead of moving the loops two needles sideways at a time, they might be moved only one needle at a time; but the ordinary work is four loops moved and two needles narrowed. The transfer of the four extreme loops on either side of the knitted web for the purpose of producing a narrowing, is effected by means of the coverers, shown at C in Figs. 4854 and 4864. These are small pointed instruments, having each a groove on the under side, as in Figs. 4856 to 4858, by which the needle head and beard can be covered. Four of these coverers, fixed at the same pitch or gauge as the needles, are carried in a small slide E, Figs. 4864 and 4885, which slides upon the rocking slide-bar F extending across the machine in front of the row of needles; there is one of these slides at each end of the bar, the four coverers being opposite to the four outer needles on each side of the knitted web. When a narrowing is to be made, the coverers advance together towards the needles until the points of the coverers C reach a little over the point of the beards of the needles N, as in Fig. 4876, at the same time the sinkers S are lifted up. The coverers are now depressed at the points or tilted downwards, so that their points enter into the grooves in the stems of the needles, and they cover and press down the beards of the needles, as in Fig. 4877. The needles and coverers then retire together, and the points of the coverers enter into the loops on the needles, Fig. 4877. The loops slide along the coverers as these continue to retire with the needles, being held forwards by the face of the knocking-over

bits K until the heads of the needles have retired behind the face of the knocking-over bits, as in Fig. 4878; in this way the loops are slipped off the needles and transferred entirely to the coverers, on which they hang, as seen in Fig. 4878. The coverers are next elevated at the points, or tilted upwards, Fig. 4879, so as to be clear of the needles and the knocking-over bits.

They are now traversed laterally, or, technically speaking, shogged, a distance of two needles towards the centre of width of the web, carrying with them the four loops they have picked up, and they are then depressed again upon the heads of the four needles over which they have now been brought, as in Fig. 4880. Of these four needles the two outer have no loops under their

4876.



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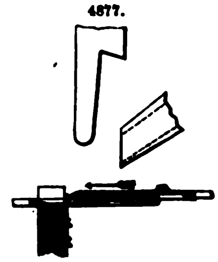

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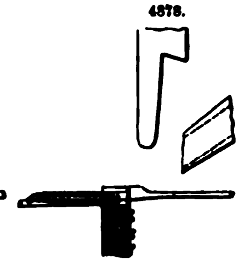

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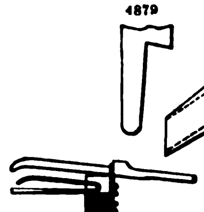

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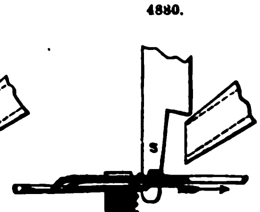

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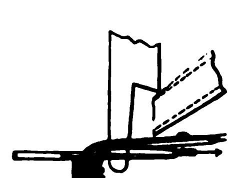
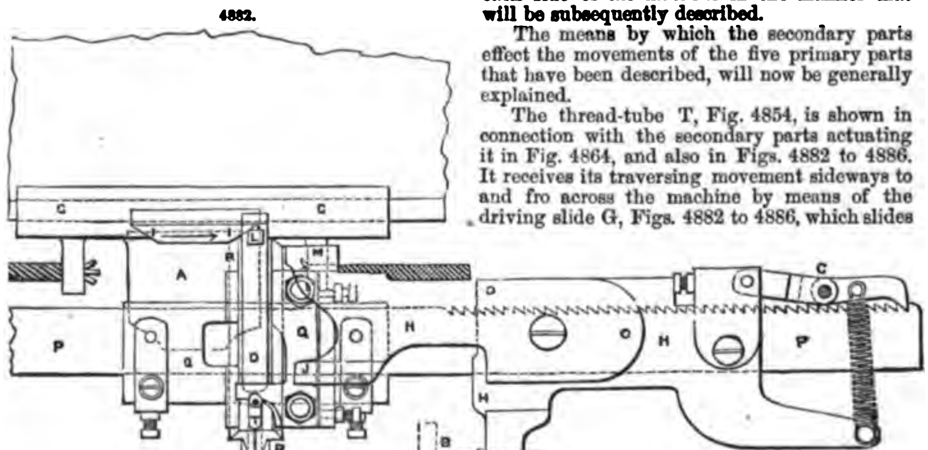


beards, while each of the two inner ones has a loop hooked under its beard, as shown in Fig. 4880 The sinkers S now descend, and the needles and coverers together advance; and the loops being held back by the tails of the sinkers, slide along the coverers as these are withdrawn, Fig. 4880. The needles and coverers continue to advance together, until the loops slide off over the points of the coverers, as in Fig. 4881, and are thus again transferred from the coverers to the needles. The coverers then retire to the position they were in originally, as seen in Figs. 4864 and 4885. This narrowing operation is performed usually on both selvedges of the web simultaneously, and at the same time the length of the traverse of the thread-tube T is reduced to two needles narrower on each side of the machine in the manner that will be subsequently described.

The means by which the secondary parts effect the movements of the five primary parts that have been described, will now be generally explained.

The thread-tube T, Fig. 4854, is shown in connection with the secondary parts actuating it in Fig. 4864, and also in Figs. 4882 to 4886. It receives its traversing movement sideways to and fro across the machine by means of the driving slide G, Figs. 4882 to 4886, which slides

4882.



along the top bar of the machine, Fig. 4852. This slide has a cord attached to it at each end, and the two cords are led round guide-pulleys and brought together at the left-hand side of the machine to a double-grooved pulley D, Fig. 4852, called the drawing-across pulley, which is carried on the left end of the cam-shaft H of the machine. In Figs. 4887 to 4891 are shown side views of the pulley, and in Fig. 4890 a back view. Each cord has an iron bob at the end, and in Fig. 4887 the right-hand cord-bob is shown just ready to be taken hold of by the notch J that is made across the two

grooves in the pulley. As the pulley revolves, this notch takes hold of the cord-bob and thus draws round with it the cord, as in Fig. 4888, thereby drawing also the driving slide G, Fig. 4882, towards the right-hand end of the machine. Meanwhile the other or left-hand cord-bob has been drawn up to the periphery of the pulley, Fig. 4888, but not until after the notch has passed it, so that it is not taken hold of during this revolution. When the pulley has revolved further, as in Fig. 4879, a stud projecting from the side of the tongue J, which is hinged in the circumference of the pulley, impinges on the fixed incline L, bolted to the frame of the machine, Fig. 4890; the tongue J is thus raised, and throws out or disengages the cord-bob, which falls down into the trough below, thus stopping the traverse of the slide G that is drawn by the cord, Fig. 4882. During the next revolution of the drawing-across pulley it will draw the left-hand cord and then disengage it in the same way when the traverse of the slide is completed. Thus during alternate revolutions, the slide driving the thread-tube is drawn across the machine from left to right and then from right to left. The position of the fixed incline L, Figs. 4887 to 4890, is adjustable for disengaging the cord-bobs at the proper point, according to the length of traverse that is required for the slide G. On occasion of a narrowing having to be made, as the slide G is then required not to make its traverse, the disengaging lever M, Figs. 4890, 4891, is brought up against the side of the drawing-across pulley so as to raise the projecting stud of the tongue J, and hold the tongue up through the length of the arc of the lever, as shown in Fig. 4891; it thus prevents the notch in the pulley from catching the cord-bob in this revolution of the pulley. When the narrowing is completed, the lever M is withdrawn again, as shown by the dotted line in Fig. 4890, and is then clear of the stud on the tongue J.

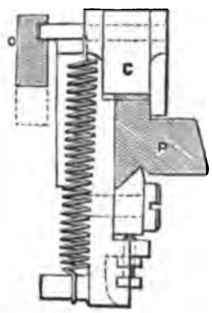
The slide G, driving the thread-tube T, Figs. 4882 to 4886, carries an incline I projecting in front called the thread-layer incline, which drives with it across the machine the horizontal thread-slide Q, sliding on the bar P that extends across the machine. This horizontal slide carries a vertical slide R, holding the thread-tube T; and the incline I drives the horizontal slide Q by bearing against the inclined top of the vertical slide R, Fig. 4882, which is held up in its place by a latch D until near the end of the traverse. The latch is then unlatched by an incline J projecting from the thread-layer stop H; but by means of a peg L projecting from the vertical thread-slide R, and resting upon the raised ledge M on the stop H, the vertical slide R is still held up until the moment that the horizontal slide Q is stopped by the stop H. At that same moment the peg L clears the ledge M; and the vertical slide R with the thread-tube T is then driven down between two of the needles, as shown in Figs. 4885, 4886, by the incline I acting upon the inclined top of the slide R. For the return traverse of the horizontal thread-slide Q, the thread-tube and its vertical slide R are lifted again by the thread-layer lifting bar U, Fig. 4885, which extends all across the machine; this lifts the slide R in whatever position across the machine it may happen to be, by means of the peg L projecting forward over the bar. The lifting bar U is carried by the two front arms of the rocking shaft, which has a third arm projecting backwards, and acted upon by a cam on the cam-shaft. The sinkers S, Fig. 4854, are free to slide up and down, and are held sideways at their upper ends in grooves in the front and back bars P and W, Figs. 4864 and 4885. In the operation of knitting they are driven down or sunk, each in succession, by the curved sinker incline A, Figs. 4885, 4886, which is carried by the traversing slide G; the incline A, as it traverses, drives the sinkers down by acting on the upper edge of that portion of them which is between the two grooved bars P and W, as shown in Figs. 4865 and 4885. The descent of the sinkers thus follows closely the laying of the thread by the thread-tube as it traverses across the machine. Each sinker is held from falling, before the sinker incline drives it down, by a sinker spring V, Fig. 4885, which latches it up in that position by taking into the notch at the back of the sinker near the top, as shown in Fig. 4864, and this same sinker spring assists the sinker in falling at the end of its descent, by bearing against the inclined top of the sinker, as shown in Fig. 4885. The sinkers are stopped at the end of their descent by the sinker lifting-bar X, Figs. 4864 and 4885; and they are all simultaneously lifted when required by the same bar, which is itself lifted by a rod at each end passing down to a rocking shaft that is acted upon by a cam on the cam-shaft. The sinkers are all lowered simultaneously when required by the sinker lowering-bar Y, which lowers them by its under edge bearing upon the projection in front of each sinker; this bar is lowered by two rods and a rocking shaft and cam, in somewhat the same manner as the sinker lifting-bar is raised.

The needles, N, Fig. 4854, are fixed in a bar Z at the back, Figs. 4864 and 4885, and rest in front on the upper edge of the knocking-over bar which holds the knocking-over bits K; the needles slide on the knocking-over bar as they retire and advance. The retiring and advancing are effected by a rocking shaft Z, Fig. 4853, the two upper arms of which are joined to the back of the needle-bar, and the one lower arm is acted upon by a cam on the cam-shaft H. The presser-bar B, Figs. 4864 and 4885, which, in descending, presses the beards of the needles down into the groove in their stem, as shown in Fig. 4871, receives its movements from the same rods and rocking shaft that move the sinker lowering-bar Y, the pressing motion of the bar B being effected by a second cam.

The narrowing movements of all the primary parts except the coverer, are produced by the same mechanism that effects the movements for knitting the web, but by a different set of cams on the same shaft. The movements of the coverers in advancing, depressing, elevating, and withdrawing them, are effected by the arrangement shown in Figs. 4852, 4853, consisting of a slide-bar F carried between centres which allow the coverers C to be depressed and elevated at the points by means of a lever A; this lever is also shown in Figs. 4896 to 4901, and is actuated by the cam B. The centres carrying the slide-bar F, Figs. 4852, 4853, 4864, and 4885, are themselves carried in a rocking frame, which allows the coverers to be advanced and withdrawn by a cam for that purpose.

The coverer slides E, Figs. 4864 and 4885, which are also shown by a dotted line E in Figs. 4882 and 4886, are traversed or shogged along their slide-bar F by the pin B carried in the

4883.



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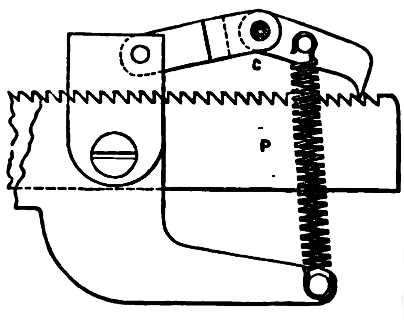
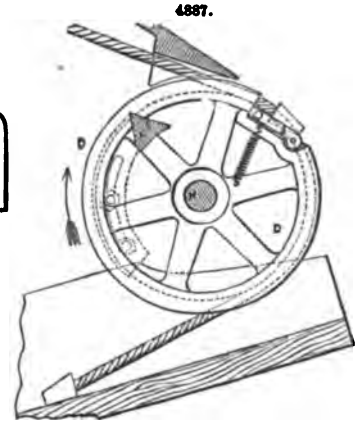


4887.



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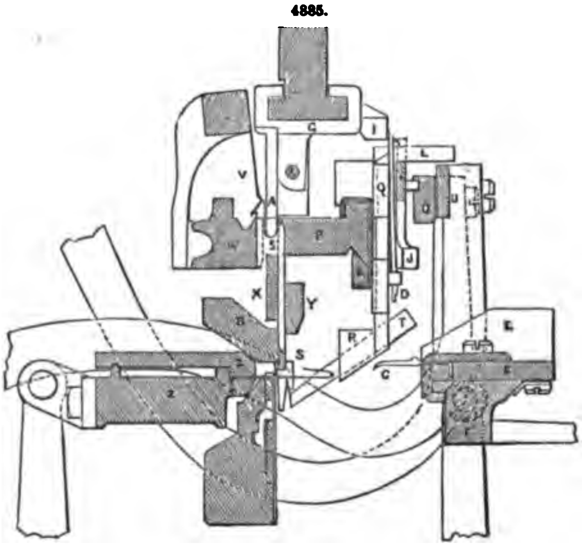

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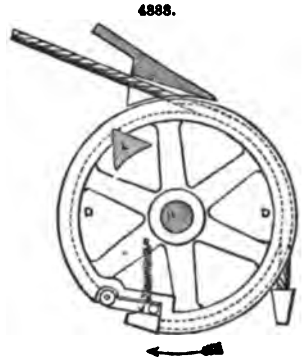
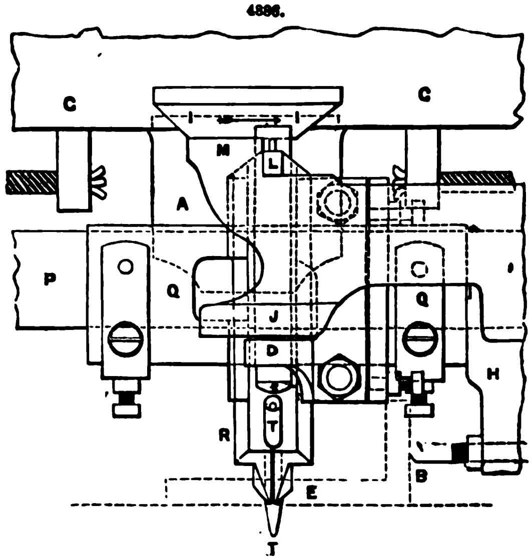
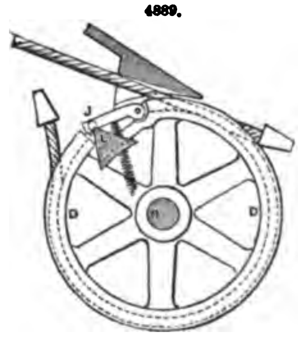


4886.

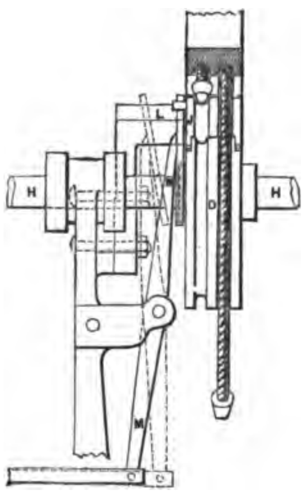


4889.

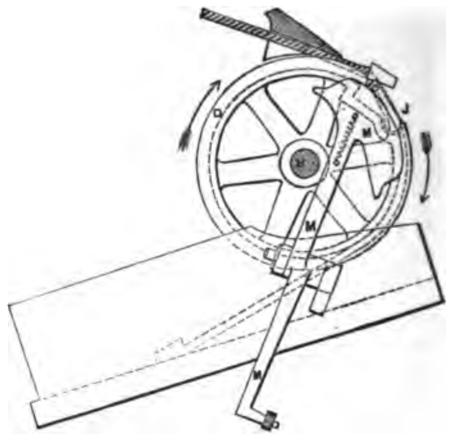


lower part of the thread-layer stop H at each side of the machine; when the coverer slides are in position to be shogged, the pin B abuts against their side and pushes them along the slide-bar

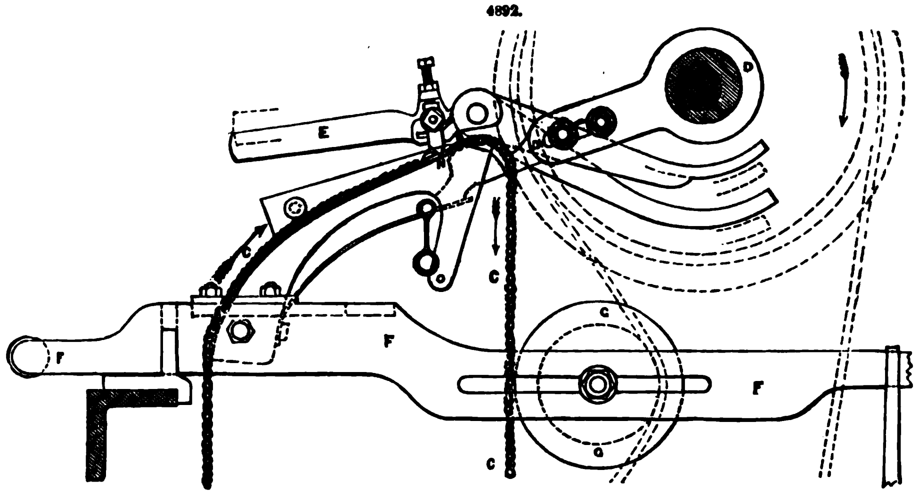
4890.



4891.



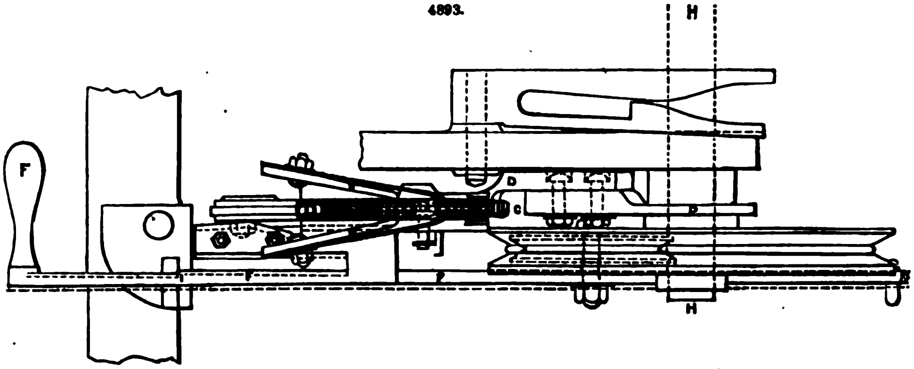
4892.



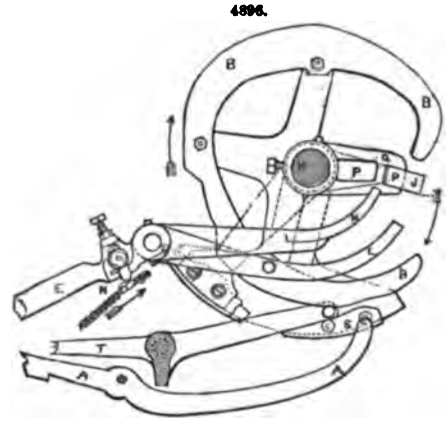
towards the centre of width of the machine. The thread-layer stops H are themselves shogged along the bar P, on which they slide by the action of the shogging ratchet C, Figs. 4882 to 4884. This works as a compound knee-lever into the ratchet-teeth in the slide-bar P; thus when the joint C is lifted, as shown in Fig. 4884, the ratchet takes a tooth, and then when the joint is lowered, as in Fig. 4882, it shogs the thread-layer stop H along the bar P, and thereby shogs also the coverer slide E and the thread-layer slide Q carrying the thread-tube T. The traverse of the thread-tube is accordingly stopped two needles earlier on each side of the machine by the stops H. The lifting of the shogging ratchet C, Fig. 4884, is done by the bar O, Figs. 4883 and 4885, which is actuated by a cam, and lifts the pin of the ratchet-joint; it holds the joint up until the coverer slides E, upon their rocking frame, have been brought into line with the pins B, and the joint is then lowered again by the bar O, whereby the coverer slides are shogged laterally through the required distance. The shape and length of the article that is being knitted are regulated by an endless pitch-chain of peculiar construction which, though believed by the writer to be little used in England, is frequently employed in France, and is called there "chain Vaucanson," after its inventor, the great engineer Vaucanson. This chain, shown at C, in Figs. 4892, 4893, is shown full size in Figs. 4894, 4895. It is drawn towards the cam-shaft H of the machine, Figs. 4892, 4893, through the distance of one link for each revolution of the shaft by means of the eccentric and ratch t D. Immediately above the chain is the narrowing handle E, the lifting of which into the position shown by the dotted lines during one revolution of the shaft H, will cause the machine to make a narrowing during that revolution. The lifting of this narrowing handle can be done by hand, if required, but it is usually effected by a link N inserted in the chain. This link, called a narrowing link, has on its upper surface a projecting incline, Fig. 4894, which, when drawn under

the narrowing handle, lifts it, as shown in Fig. 4898, and thus makes a narrowing in the knitting. Another sort of link S is also shown in Figs. 4894, 4895, called a stopping link, having an incline projection at its side; this link is inserted in the chain wherever it is wished that the machine shall be stopped, and the stoppage is effected by the stopping link unlatching the sliding handle F which carries the tightening pulley G. This pulley pressing against the driving gut of the machine, gives tension requisite for driving it, as shown in Fig. 4892, the stopping handle being latched in that position by the projecting lug I on its side catching against the guide in which it is carried, as shown in Fig. 4893 · but when the stopping link cants the handle, as in Fig. 4895, the

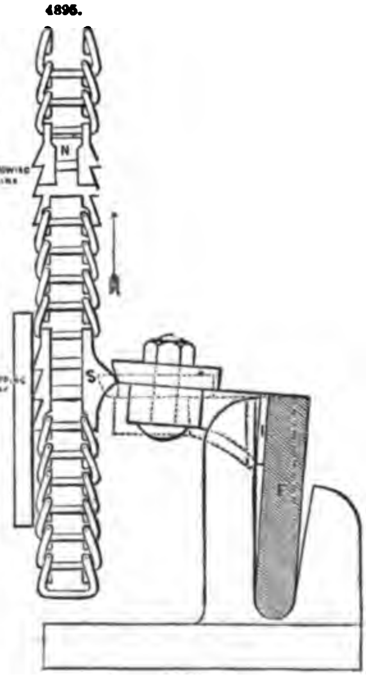
4893.



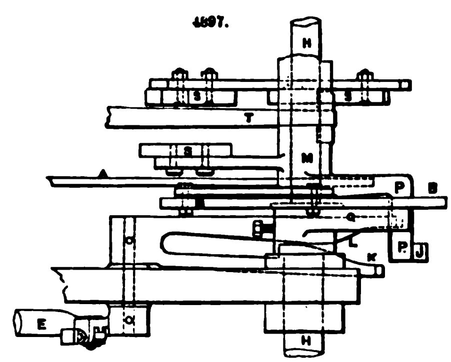
4896.



4894. 4895.



4897.



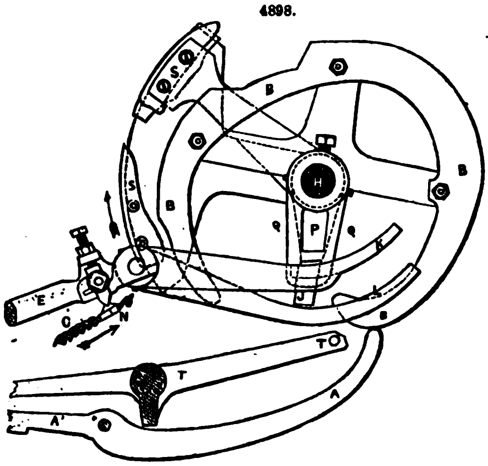
catch I is liberated, and the driving gut is thereby slackened and the machine stopped. Each plain link in the pitch-chain C represents therefore one row of loops or one course in the knitting, and each narrowing link represents a narrowing, and each stopping link represents the completion of the piece to be knitted.

The change of all the movements of the machine, from making web to narrowing, is accomplished by having two different sets of cams mounted on a tube, which is free to slide lengthways upon the cam-shaft, but is driven round with it, as shown in Figs. 4896 to 4901. The several cams are so arranged in their distances sideways along the sliding cam-tube M, that when the cam-tube is at the right-hand side of the machine, as shown in Figs. 4896, 4897, and the back view,

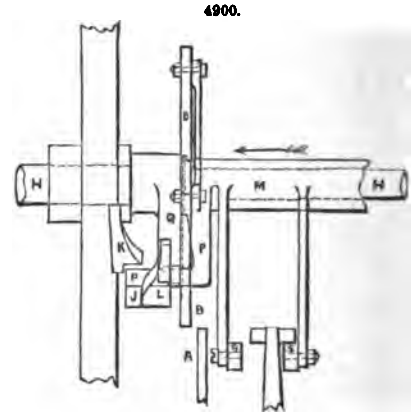
Fig. 4900, the set of cams for web making acts on the various levers and arms of the rocking shafts, while the set of cams for narrowing passes clear on the right-hand side of them. But when the cam-tube M with its two sets of cams is traversed along the cam-shaft H above $\frac{3}{8}$ in. towards the left side of the machine, as shown in Figs. 4898, 4899, and 4901, then the set of cams for narrowing acts in turn upon the levers and rocking shafts, and thus cause a narrowing. When the cam-tube is traversed back again to the right-hand side of the machine, the making of web is resumed and continued until the cams are again traversed to the left.

The longitudinal traversing movement of the cam-tube is effected by an arm P attached to the cam-tube M, and driven round by the cam-tube driver Q, which is secured upon the cam-shaft H. Below the arm P are a pair of helical inclines K and L, Figs. 4900, 4901, the upper one K for traversing the cam-tube from right to left, and the lower one L for traversing it back from left to right. This pair of helical inclines are attached to an axle of the narrowing handle E, Figs. 4892, 4893, so that when the handle is raised they are lowered, and *vice versâ*. Thus when the narrowing handle is lifted for narrowing, and the helical lowered, as in Fig. 4898, the cam-tube arm P will be acted upon by the upper incline K, as shown in Fig. 4901, and the cam-tube M will be traversed to the left-hand, as in Figs. 4899 and 4901, causing several narrowing cams to

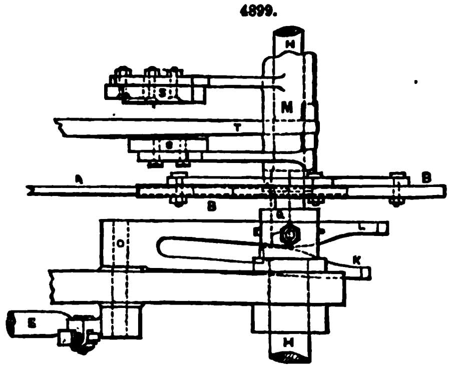
4898.



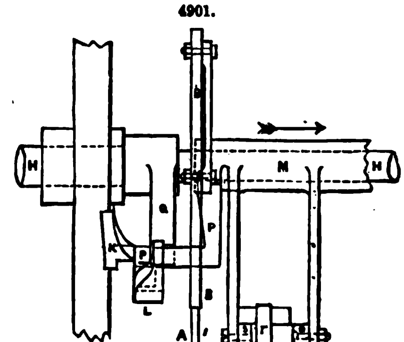
4900.



4899.



4901.



come into action upon their respective levers. If on the next revolution of the cam-shaft H, the narrowing handle is lowered for web making, and the helical inclines raised, as in Fig. 4896, the lower incline L will then come into contact with the stud J on the cam-tube arm P, as shown in Fig. 4900, and will traverse the cam-tube M back again towards the right-hand end of the machine, as in Figs. 4897 and 4900, and the cams for the web-making movements will come into operation so long as the narrowing handle is not raised again, the stud J will continue to pass below the upper helical incline K and alongside of the lower one L, as in Fig. 4900, and the cam-tube will not be traversed; but whenever the narrowing handle is lifted the web-making movements will be stopped, and a narrowing will be effected. There are altogether twelve cams upon the cam-tube M for producing the various movements required in knitting and in narrowing, and of the three cams shown in Figs. 4896 to 4901, the cam B acting on the lever A produces the elevation and depression of the coverers in narrowing, by tilting the coverer slide-bar F, Figs. 4864 and 4885, upon the centres on which it is carried in the rocking frame, while the pair of cams S S acting alternately upon the lever T, Figs. 4896 to 4901, produce the vertical movements of the presser-bar B and the sinker lowering-bar Y, Figs. 4864 and 4885.

In conclusion, with reference to the speed of working of the self-acting knitting machine, as compared with the older methods of knitting, it may be taken that a skilled knitter with ordinary knitting pins will knit about sixty stitches or loops a minute in knitting the leg of a stocking. A skilled framework knitter will with his hand-frame knit on the same work about 5400 stitches a minute, whereas a girl will on the same work attend to three of the self-acting machines, each making fifty courses a minute of 13½ in. width and 20 stitches an inch, the three machines together thus making 40,500 stitches a minute. A large number of these self-acting machines are now in use, having been in successful operation for several years.

KYANIZING.

A method of preserving wood from dry-rot, introduced by Kyan. The operation consists in soaking the wood in a solution of corrosive sublimate, which forms a new chemical compound with the albumen, and prevents the destructive power going on. At first the proportions used were 1 lb. of corrosive sublimate to 4 gallons of water, but on subsequent trials it was found that the wood absorbed about 6 or 7 lbs. of the salt a load, which would have rendered the process too costly for general use. Ultimately the proportions were reduced to 1 lb. of corrosive sublimate to 10 gallons of water when a maximum strength was required, and 1 lb. to 15 gallons of water when a minimum; with the latter proportion 1¼ lb. was sufficient for a load of timber containing 50 cub. ft. The solution is contained in a wooden tank, put together so that no metal of any kind can come in contact with it. The salt dissolves best in tepid water. The time required to saturate the timber depends on its thickness. Twenty-four hours are usually allowed for each inch in thickness of boards and small timber. Large timber requires from a fortnight to three weeks.

Notwithstanding that corrosive sublimate is highly destructive to all forms of animal life, Kyan's process has not been found effective either against the worm or white ant, though it appears to have had some effect in retarding the dry-rot. It is now seldom used, and other methods have replaced this once over-praised remedy.

Another process formerly in great favour was that by Sir William Burnett. It had for its object, in common with kyanizing, the coagulation of the albumen of the wood. Burnett used, in a wooden tank, a solution of *chloride of zinc*, in the proportion of 1 lb. to 4 gallons of water.

Timber requires to be immersed for about two days for each inch in thickness, and afterwards taken out and left to dry from fourteen to ninety days.

The process is applicable to canvas, ropes, and similar articles, which require to be immersed in the solution for about forty-eight hours, and then taken out and dried. The process on wood may be more expeditiously performed by means of the hydraulic press, with which the solution of chloride of zinc is forced into the timber. Where the timber can be kept tolerably dry, it is no doubt beneficial, as it tends to harden the wood, and renders it partially incombustible, and it is also supposed to prevent the attacks of insects, which are found to commit great ravages in the interior fittings of vessels.

One of the most successful means yet tried of preserving timber, whether from the effects of exposure to the weather, dry-rot, or the attacks of worms and insects, is by impregnating its substance with *creosote*, one of the products obtained from the distillation of coal-tar, and possessing powerful antiseptic properties. When injected into the wood, creosote has the effect of coagulating the albumen, thereby preventing decomposition, and the bituminous oil with which it is combined enters the capillary tubes of the wood, closing up its pores so as to exclude both air and moisture, and the noxious properties of the oil have the effect of repelling both worms and insects.

Several attempts have been made from time to time to introduce creosote into notice as a preservative of wood; but it was not until 1838 that it became extensively used. The opinions of engineers, who have used it for the preservation of railway sleepers in all climates, both at home and abroad, have been strongly in its favour, and its power of enabling timber to resist putrefaction, and to a considerable extent of repelling the attacks of the sea-worm and white ant, when properly applied and in sufficient quantity, has been placed beyond doubt.

It was found, however, by Stevenson to have failed in repelling the attacks of the *Limnoria terebrans* at Invergorden in Scotland, where the piles of a jetty, erected in 1858, and which had been thoroughly creosoted, "were very much eaten and perforated" in about four years after being fixed; and Stevenson, in a paper "On the Ravages of the *Limnoria terebrans*," read before the Royal Society in 1862, gave it as his opinion that the process of creosoting preserved timber from the attacks of marine insects only so long as the oil existed as a film, or coating, on the outside of the timber. When the attrition caused by the motion of the sea removed this film or coating, and exposed the fibrous surface of the timber, the insects would then attack and perforate it whether it was creosoted or not, its search being for a fibrous substance in which to burrow.

The mode of impregnating wood with creosote adopted by Bethell is to dry out the moisture from the pores of the timber by passing all the smoke and products of combustion from the burning fuel through the drying house so as to pass between the different pieces of wood, thus drying and smoking them at the same time, after the manner that hams, bacon, and fish are smoked and cured. By this mode of drying, wood that has been cut down for several months loses in ten hours about 8 lbs. in weight a cubic foot; and if immersed in hot creosote oil in open tanks directly after it leaves the drying house, and while warm, it quickly absorbs the oil to the extent of 8 or 9 lbs. a cubic foot. Another method is to place the timber, after it leaves the drying house, in a wrought-iron cylinder with closed ends, and to force in the heated oil at a pressure of about 170 lbs. to the square inch. The heat is kept up in order to prevent the creosote from crystallizing in the pores of the wood during the process. Under this system, pine, fir, or other soft wood easily absorbs from 10 to 12 lbs. of oil a cubic foot. For railway works, Bethell considered 7 lbs. a cubic foot sufficient, but for marine works he recommended that 10 lbs. of the oil a cubic foot, at least,

should be forced into the wood, and some engineers have required even 12 lbs. Into oak and other hard woods, particularly those of India, it is sometimes difficult to force more than 2 or 3 lbs. of the oil, even by the heaviest pressure. The Saul-wood of India was seldom penetrated more than ¼ of an inch from the surface.

Another method which is applicable to the preservation of straight-grained or porous timber, was introduced some years ago by M. Boucherie, a French chemist. Instead of using great pressure to impregnate the timber, as in creosoting, he applied a moderate pressure only to one end of the log or tree, which had the effect of expelling the sap, and permitted the pores of the timber to be filled with the preserving fluid, which consisted of a solution composed of 1 part of *sulphate of copper* to 100 parts of water by weight; the specific gravity of the solution at 60° Fahr., when of proper strength, being 1·006, or nearly so. The process is as follows;—A water-tight cap is placed on one end of the log to be saturated, and the solution is introduced within it by a flexible tube. The pressure required not being more than from 15 to 20 lbs. on the square inch, it may be obtained in a very simple way by raising the tank which contains the solution to the height of 30 or 40 ft. from the ground. When the pressure is applied, the sap runs in a stream from the opposite end of the log; and a ready means exists of discovering when it is exhausted and the whole length of the timber penetrated by the solution, by simply rubbing the end with a piece of prussiate of potash, which will leave a deep brown mark when brought into contact with the sulphate of copper.

There are certain kinds of timber which are impenetrable by the solution applied in the manner described. It answers best with newly-felled beech, birch, larch, Scotch pine, alder, elm, or poplar. Trees felled any time between November and May can be prepared in the latter month, but when cut down in May, or any month between that and November, they should be prepared within three weeks of the time of felling.

It was found, during the preparation of large quantities of timber for the French navy and railways, that the time necessary for the operation depends both on the length of the tree and on the description of timber. Trees of 40 ft. in length, prepared at Fontainebleau for the French navy, required from eight to ten days to become sufficiently impregnated; whereas, for a length of 9 ft. only, the process was accomplished in twenty-four hours. One great advantage attending Boucherie's method is the small cost of the apparatus required.

Boucherie also used the impure pyrolignite of iron, which was found not only to preserve the wood from decay, but to harden it to a very high degree.

To Cure the Dry-Rot.—When once this disease has set in, the cure is very difficult, as the whole place where the timber is situated becomes infected. Measures should be immediately taken to provide proper ventilation, and to cut off the access of moisture; the diseased parts of the timber should be cut away, and every particle of fungus removed by brushing the walls and adjoining timbers; after which a wash should be applied to all infected places, consisting of some solution that will destroy any germs of fungi that may have escaped the brush.

Davy proposed corrosive sublimate, which should not be of less strength than 1 oz. to every gallon of water, laid on hot.

A solution of sulphate of copper, in the proportion of about 8 oz. to a gallon of water, is said to make an excellent wash, and is cheaper than the corrosive sublimate.

A mixture of sulphate of copper and sulphuric acid in the proportion of 1 lb. of each to 6 gallons of water has been found to preserve timber for nearly twice the ordinary period. The sulphate of copper should first be dissolved in 1 gallon of boiling water, and the remainder of the water and sulphuric acid added afterwards.

Sulphate of iron has been used as a wash for timber, but it is not so efficacious as sulphate of copper.

Oil of tar also makes an excellent wash for timber that is infected with the dry-rot, but the smell is very much against its use in situations that are inhabited.

When a mere antiseptic is required, probably one of the best that can be used is carbolic acid in its crude state. The surface of the timber and the place on which it rests should be washed over with it; but, like oil of tar, the smell is objectionable in some situations.

To prevent the attacks of the sea-worm, the most effectual remedy is to thoroughly impregnate the wood with creosote. Nails closely driven over the surface of piles below high water, when carefully performed, have been found to protect them from the attack of these animals. This and covering the surface with sheet copper, are perhaps the only methods known of resisting the attack of the *Limnoria terebrans*.

The only timber that will resist the white ant is teak (*Tectona grandis*) and ironwood (*Sideroxylon*). The Jarrah wood of Australia sometimes escapes their ravages, but all other woods are attacked by them. The only effectual remedy has been creosote; but even that, if it has not penetrated the wood thoroughly, will not avail.

Corrosive sublimate, chloride of zinc, salts of lead, even creosote and carbolic acid, have all been tried at St. Helena with no more effect than to retard the destruction of the wood for a few months.

For the true ant, or *Formica*, arsenic has been used in the West Indies; and Thunberg has found cajeput oil effectual in destroying the red ants of Batavia: he used it to preserve his boxes of specimens from them. When ants were placed in a box anointed with this oil, they died in a few minutes.

Books on Preserving Timber:—Bowden (W.), 'On Dry-Rot,' 8vo, 1810. Mathew (P.), 'On Naval Timber,' 8vo, 1812. Chapman (W.), 'A Treatise on the Preservation of Timber,' 8vo, 1817. Lingard, 'On Timber,' 8vo, 1827. George (J.), 'The Cause of Dry-Rot Discovered,' 8vo, 1829. Birkbeck (Dr.), 'On the Preservation of Timber by Kyan's Process,' 8vo, 1834. Dickson (Dr.), 'A Lecture on Dry-Rot,' 8vo, 1838. Faraday (M.), 'On the Practical Prevention of Dry-Rot in Timber, 8vo, 1838. Tredgold's 'Carpentry,' by J. T. Hurst, cr. 8vo, 1871.

LAMP, SAFETY. FR., *Lampe de sûreté*; GER., *Sicherheitslampe*; ITAL., *Lampada di sicurtà*.

In mines subject to the accumulation of firedamp it has always been desirable to have methods of lighting incapable of communicating combustion to the surrounding atmosphere. The primitive method of effecting this consisted in the use of the steel mill, a circular piece of steel fixed to the axis of one of a pair of multiplying wheels, arranged in a frame so as to be rotated quickly against the sharp edge of a flint, and so produce, by a succession of sparks, a feeble light. This uncertain, expensive, and, under certain circumstances, dangerous plan, was eventually superseded by the lamp invented by Sir Humphry Davy. The Davy lamp owes its comparative safety to its having the flame surrounded with a cylinder of wire gauze. When it is immersed in an explosive atmosphere the inflammable gas enters from without, and burns in the gauze cage, but, in consequence of the cooling power of the wire gauze, no flame can pass outward to ignite the surrounding atmosphere. The miner is therefore warned of his danger by the appearance of the lamp.

The Davy lamp is not entirely safe, and the unsafety of this and other lamps so much trusted and so largely used in our coal mines, has been indisputably proved by the accidents which have occurred, and the careful and systematic experiments made on the lamps. The cause of this failure, particularly with the Davy, Clanny, and Stephenson lamps, briefly stated, is that, although while in a still atmosphere of explosive gas they only burn or heat so much air or gas as the natural ventilation caused by their flame and the flame of the burning gas brings to them, yet when immersed in a current moving in a determinate direction they are compelled to burn a quantity of gas represented by the area of the cross-section of the open parts, and by the velocity of the current passing: for instance, a Davy lamp will consume about 13 cub. ft. of pure air an hour; suppose this consumption to be quadrupled when the lamp is placed in a quiet atmosphere of explosive gas, equal to a consumption of 50 cub. ft. an hour, but placed in a current of 10 ft. a second, what will its consumption be? The sectional area of a Davy lamp cylinder will be $7\frac{1}{2}$ sq. in., $\therefore$ consumption $= \frac{7\frac{1}{2} \times 60 \times 60 \times 120}{1728} = 1860$ cub. ft. an hour, about thirty-seven times what it was in the other case. Now the consumption of thirty-seven times as much gas means the evolution of thirty-seven times as much heat, and this in the same time, therefore the gauze and surrounding air have to radiate and conduct away thirty-seven times as much heat a second, minute, or hour. But the radiating and conducting powers of iron and air are not infinite, hence a point arrives at which the task is too great, and the gauze and in due course the surrounding gas are so highly heated as to explode. The danger is the greater when it is further considered that there is an action somewhat similar to that of the fan blast on a smith's fire, and that the current clears away the products of combustion, so that they do not impede the consumption of the next following gas; thus a much more intense heat is produced.

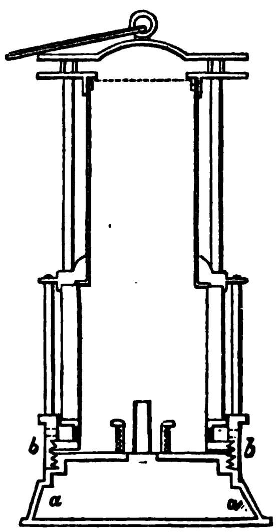
Hann's safety lamps are constructed on the plan of protecting the flame of the lamp, and the whole space included within the wire gauze, from the currents of air or gas passing outside it. Thus, instead of allowing air to pass freely through all parts of the gauze, as in the Davy lamp, or to pass only through a gauze above a short glass cylinder, as in the Clanny, or to pass to some extent under and freely over the ends of a glass cylinder within a gauze cylinder, as in the Stephenson, no air is allowed to enter except through apertures properly placed, and air is only allowed to escape from the upper end, and not from any part of the sides of the gauze, both the inlet and outlet being adequately protected from any *direct* current of air or gas.

Hann's improvements are applied both to the original Stephenson and the Clanny lamps. The construction of the former lamp differs from a Davy only in the following particulars; within the gauze is a tall glass chimney surmounted by a copper perforated cap, the air enters the lamp through some apertures below the glass, and through whatever open space may exist between the notched ring supporting the glass and the outside frame, and escapes not only from the end of the gauze cylinder, but from the sides of the perforated cap.

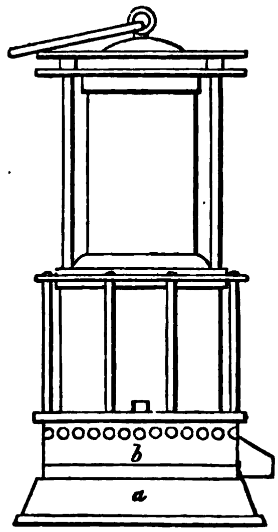
In Hann's lamps the inlet and outlet are prescribed and shielded in the following manner:—First, in the improved Stephenson, or No. 1 lamp, of which Figs. 4904, 4905, are elevations, Fig. 4906 a section, the inlet is through the apertures at *b*, the air is obliged to pass through the lower part of the gauze cylinder, Fig. 4907, and then through the slits in the screw ring *c*, shown enlarged at Fig. 4910. Upon the flat part of the upper edge of this screw ring stands the glass cylinder *d*, which reaches nearly to the top of the gauze cylinder; it is surmounted by a brass tube *e*, fitting to it accurately, but not tightly, by a swedged end; this metallic tube goes right up under the top plates, and carries the whole escaping air up the end of the gauze cylinder through which alone it can escape. This outlet is protected by an arrangement of a pair of parallel plates, by means of which a current, whatever be its direction, cannot strike this point of outlet direct, it can only do so by a reflex or diverted current, yet the products of the combustion have ample space for their escape. The other points deserving notice are that the upper edge of the screw ring *c* carries a projecting rim, which better secures the glass cylinder. If, from any circumstances advantageous, the common device of a cone can be put in the metallic tube, which may sometimes improve the current in the lamp. Fig. 4906 shows the inlet-holes turned upwards into a cavity within the boss *a*, by which means the current affects the lamp still more indirectly. Fig. 4908 is a horizontal section through this boss *a*, and shows the vertical air-holes; the niche *a* is made for the seam of the gauze *a′*, Fig. 4907, to fit into. Fig. 4911 is the lamp-glass, shown also at *d*, Fig. 4906.

Figs. 4902, 4903, illustrate the No. 2, or improved Clanny lamp, in which the air enters through apertures in every respect the same as those in the No. 1, it then passes through a screw ring, which is very similar to Fig. 4910, and which carries a strip of wire gauze, covering all the openings through it. This screw ring supports a strong glass cylinder, of about 2¼ to 2¾ in. in length, the upper end of which is enclosed in a framework similar to that of the ordinary Clanny. A brass tube, as in the No. 1, surmounts the glass. The brass tube carries at its lower end a flat, wide flange, which rests on the glass, and thus, when the lamp is put together, it is impossible for the tube to move

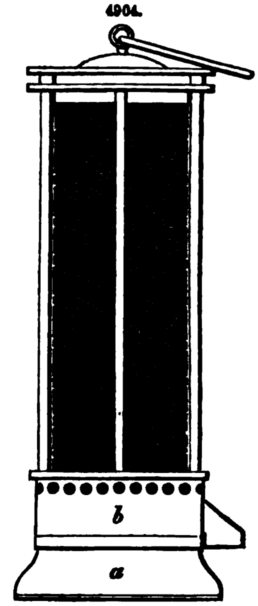
4902.



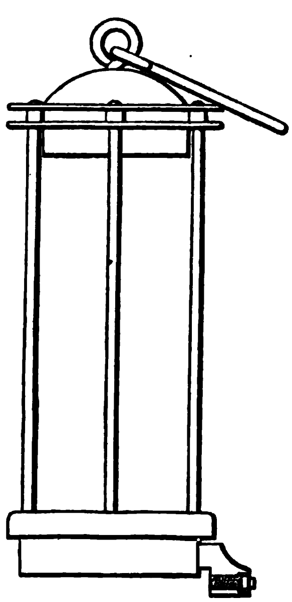
4903.



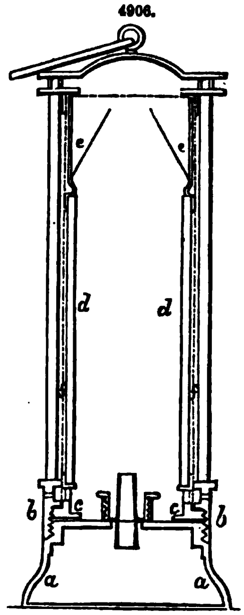
4904.



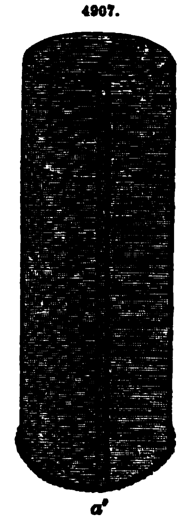
4905.



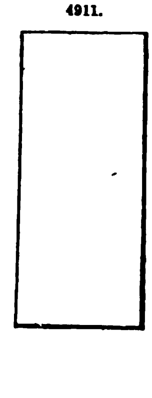
4906.



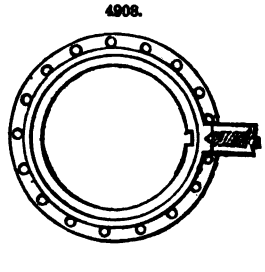
4907.



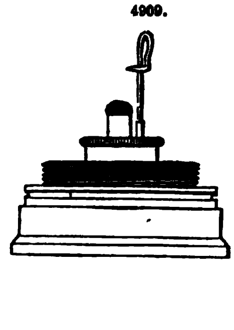
4911.



4908.



4909.



4910.

while the glass remains intact. The upper end of this brass tube is closed by a plate of perforated copper brazed to the tube. The outlet is protected in the same manner as in the No. 1.

In both lamps it is advantageous to keep the top of the gauze and brass cylinders a little below the position shown in the figures; they are thus removed still farther from the currents of air.

The No. 1 lamp consists of six principal parts;—oil vessel, Fig. 4909, upper main frame, Fig. 4905, screw ring, glass cylinder, gauze cylinder, brass tube. No. 2 of five principal parts;—oil vessel, main frame, screw ring, glass cylinder, Fig. 4911, brass cylinder. The Davy lamp of five principal parts;—oil vessel, main frame, small ring, gauze cylinder, gauze cap. The Clanny lamp of eight principal parts;—oil vessel, main frame, lower screw ring, glass cylinder, upper screw ring, small ring, gauze cylinder, gauze cap. The Stephenson lamp has seven principal parts;—oil vessel, main frame, screw ring, gauze, glass, two copper cap-pieces. Thus Hann's lamps are rather simpler than more complex as compared with those now generally used, and yet a strong lamp is produced.

The results of these arrangements are that great safety is procured, for these lamps have successfully withstood the extreme velocity of 50 ft. a second, a velocity unknown in mines; an improved light is afforded compared with the same class of lamp; and yet the lamps are neither heavy, large, expensive, nor complicated, all very important points. They are among the few new lamps that have received the practical approval of any considerable number of mining engineers.

The relative amount of light given out by the undermentioned safety lamps was carefully determined by John Pattinson, of Newcastle-on-Tyne, and he found the following results. In each of the lamps the same kind of oil, and the same kind of wicks were used, and each lamp was trimmed so as to give the greatest amount of light without smoking. All the lamps were made by one and the same manufacturer, and the light measured by a photometer. Assuming the amount of light given by the ordinary Davy lamp to be represented by 1000, the following numbers represent the relative amount of light given out by the other lamps experimented with;—

Ordinary Davy	1000
Ordinary Stephenson	1063
Hann's Improved Stephenson	1242
Ordinary Clanny	2345
Hann's Improved Clanny	3399

Thus whilst the ordinary Stephenson lamp gives but a little more light than the Davy Hann's Improved Stephenson gives about one-quarter more light; and whilst the ordinary Clanny gives about 2⅓rd times more light than the Davy, Hann's Improved Clanny gives over 3⅓rd times more light.

LATHE. Fr., *Tour;* Ger., *Drehbank;* Ital., *Tornio;* Span., *Torno.*

See Hand-Tools. Machine Tools.

LATTICE GIRDER. Fr., *Poutre en treillis;* Ger., *Gitterträger;* Ital., *Trave all' americano;* Span., *Viga de celosia.*

See Bridge.

LAP. Fr., *Recouvrement du tiroir;* Ger., *Deckung;* Span., *Tapadura.*

See Steam-Engine. Slide-Valve.

LAUNDER. Fr., *Mahay* (en Belg.) *boisage de la sole d'une galerie d'encoulement;* Ger., *Gefluder;* Span., *Artesa (Mineria).*

The name given by miners to the trough which receives the powdered ore from the box where it is beaten.

LEAD. Fr., *Plomb;* Ger., *Blei;* Ital., *Piombo;* Span., *Plomo.*

Atomic weight, 207. Molecular weight unknown.

Lead is obtained chiefly from its native sulphuret, known by the name of galena. There are various processes for extracting the metal. One is to partially roast the ore, when a portion of the sulphur becomes sulphate of lead.

$$\underset{\text{Sulphuret of lead.}}{PbS} + \underset{\text{Oxygen.}}{2\left(\begin{matrix}O\\O\end{matrix}\right\})} = \underset{\text{Sulphate of lead.}}{SPbO_4}$$

A second portion produces oxide of lead and sulphureous anhydride.

$$\underset{\text{Sulphuret of lead.}}{2PbS} + \underset{\text{Oxygen.}}{3\left(\begin{matrix}O\\O\end{matrix}\right\})} = \underset{\text{Sulphureous anhydride.}}{2SO_2} + \underset{\text{Oxide of lead.}}{2PbO}$$

A third portion remains unaltered as sulphuret of lead.

When it is judged that oxidation is sufficiently advanced for the mass to contain the required proportions of oxide, sulphate and sulphuret, the ingress of the air is stopped, and the heat greatly increased. The sulphate and oxide of lead react upon the sulphuret; sulphureous anhydride is liberated, and metallic lead remains at the bottom of the furnace.

$$\underset{\text{Sulphuret of lead.}}{PbS} + \underset{\text{Sulphate of lead.}}{SPbO_4} = \underset{\text{Sulphureous anhydride.}}{2SO_2} + \underset{\text{Lead.}}{2Pb}$$

$$\underset{\text{Sulphuret of lead.}}{PbS} + \underset{\text{Oxide of lead.}}{2PbO} = \underset{\text{Sulphureous anhydride.}}{SO_2} + \underset{\text{Lead.}}{3Pb}$$

This is called the reaction process.

The lead may also be extracted by transforming all the sulphuret into oxide by roasting, and afterwards reducing the oxide by means of carbon, or by heating the galena directly with iron, which combines with the sulphur and liberates the lead.

Lead is of a bluish grey colour. When fresh cut it presents a bright metallic appearance, but it is quickly blackened by exposure to the air, owing to the formation of a thin film of oxide. It is soft, and leaves a streak upon paper. The density or specific gravity of pure lead is 11·44, and instead of increasing under cold-beating, as the other metals do, it decreases. Lead crystallizes in regular octahedrons, or in four-sided pyramids. These crystals may be obtained artificially. It fuses readily at about 625°; before the gas blow-pipe it may be volatilized. This metal occupies the sixth rank for malleability, and the eighth for ductility. Its tenacity is very low.

Lead in a state of fusion possesses the property of dissolving a small quantity of oxide, which tenders it brittle; but its original qualities may be restored by stirring it with a piece of charcoal. It preserves itself for an indefinite time when exposed to the air; for though a thin film of oxide forms on its surface when exposed, this film preserves the remaining metal from further oxidation. When heated, however, it readily becomes oxidized. When lead is placed in pure water exposed to the air, it absorbs the oxygen and the carbonic anhydride, and gives a hydrated carbonate of lead. The soluble salts, and especially sulphate of lime, prevent this reaction from taking place. This explains why the pipes of fountains do not become oxidized.

Hydrochloric and dilute sulphuric acid do not sensibly act upon lead. Concentrated sulphuric acid acts upon it by liberating sulphureous anhydride and producing sulphate of lead. The best solvent of this metal is nitric acid. Lead readily combines with mercury, and forms an amalgam which is liquid or solid according as the mercury or the lead predominates.

Lead is tetratomic. It combines with four molecules of two monatomic organic radicals, ethyl and methyl. The following are known;—

Ethyl lead	$\mathrm{Pb}(\mathrm{C_2H_5})^4$	Methyl lead	$\mathrm{Pb}(\mathrm{CH_3})^4$

The formula of these compounds is not uncertain; for we may substitute chlorine or iodine for a quarter of the ethyl or methyl, and this would be impossible if they contained less than four molecules of these radicals.

With the simple monatomic substances, lead always acts as a bivalent, which amounts to saying that it is never saturated. There exist

A chloride of lead	$\mathrm{Pb\,Cl_2}$	An iodide of lead	$\mathrm{Pb\,I_2}$
A bromide „	$\mathrm{Pb\,Br_2}$	A fluoride „	$\mathrm{Pb\,Fl_2}$

Lead combines also with the diatomic metalloids; with sulphur it forms a single compound; sulphuret of lead, $\mathrm{Pb\,S}$. With oxygen it combines in various proportions, hence four distinct oxides;—

A suboxide	$\mathrm{Pb_2\,\Theta}$	Red-lead	$\mathrm{Pb_3\,\Theta_4}$
A protoxide	$\mathrm{Pb\,\Theta}$	A binoxide (plumbic anhydride)	$\mathrm{Pb\,\Theta_2}$

Along with the protoxide must be placed a condensed hydrate, $\begin{matrix}\mathrm{Pb}\\ \mathrm{Pb}\end{matrix}\left\{\begin{matrix}\Theta\,\mathrm{H}\\ \Theta\\ \Theta\,\mathrm{H}\end{matrix}\right.$ to which the salts correspond. The simple hydrate $\mathrm{Pb}\left\{\begin{matrix}\Theta\,\mathrm{H}\\ \Theta\,\mathrm{H}\end{matrix}\right.$ has hitherto not been obtained, but a large number of salts are known resulting from the substitution of acid radicals for the typical hydrogen of this base.

Haloid Compounds of Lead.—Chloride of Lead, $\mathrm{Pb}\left\{\begin{matrix}\mathrm{Cl}\\ \mathrm{Cl}\end{matrix}\right.$.—Chloride of lead may be prepared by heating oxide of lead with hydrochloric acid. By this means a white powder is obtained, which, when dissolved in boiling water, crystallizes, on the cooling of the liquor, in pretty acicular crystals of a silvery lustre. This salt may also be prepared by pouring hydrochloric acid or a soluble chloride into the cold solution of a salt of lead.

$$1.\qquad \underset{\text{Oxide of lead.}}{\mathrm{Pb\,\Theta}} + \underset{\text{Hydrochloric acid.}}{2\left(\left.\begin{matrix}\mathrm{H}\\ \mathrm{Cl}\end{matrix}\right\}\right)} = \underset{\text{Chloride of lead.}}{\mathrm{Pb\,Cl_2}} + \underset{\text{Water.}}{\left.\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\Theta}$$

$$2.\qquad \underset{\text{Neutral nitrate of lead.}}{\mathrm{Pb}\left\{\begin{matrix}\Theta\,\mathrm{N}\,\Theta_2\\ \Theta\,\mathrm{N}\,\Theta_2\end{matrix}\right.} + \underset{\text{Chloride of sodium.}}{2\left(\left.\begin{matrix}\mathrm{Na}\\ \mathrm{Cl}\end{matrix}\right\}\right)} = \underset{\text{Sodic nitrate.}}{2\left(\left.\begin{matrix}\mathrm{N\,\Theta_2}\\ \mathrm{Na}\end{matrix}\right\}\Theta\right)} + \underset{\text{Chloride of lead.}}{\mathrm{Pb}\left\{\begin{matrix}\mathrm{Cl}\\ \mathrm{Cl}\end{matrix}\right.}$$

Chloride of lead is hardly soluble in cold water; it is more soluble in boiling water. Alcohol does not dissolve it at all. When heated, chloride of lead fuses before attaining red heat, and when heated further, it gives off fumes freely. When fused and cooled, it becomes a translucid mass, capable of being cut with a knife. For industrial purposes, as pigments, compounds of chloride and oxide of lead and oxychloride of lead are prepared, the true atomic composition of which is not known. All of these productions are of a yellow colour.

Bromide of Lead, $\mathrm{Pb\,Br_2}$.—This is obtained by a double decomposition, by means of a soluble salt of lead and a soluble bromide; it is insoluble in alcohol, hardly soluble in cold water, but more soluble in boiling water. Like the chloride it is obtained crystallized in pretty spangles by saturating it with boiling water and then leaving the water to cool.

Iodide of Lead, $\mathrm{Pb\,I_2}$.—This is prepared in the same way as the bromide and chloride, by

substituting an iodide in the reaction for the chloride and bromide. Iodide of lead is yellow; it is insoluble in alcohol, hardly soluble in cold water, but much more soluble in boiling water. On leaving its hot solution to cool, it crystallizes in spangles of a rich gold colour. When fused while exposed to the air, it becomes an oxyiodide by losing iodine. When heated while protected from the air, it becomes a reddish yellow, then a brick red, afterwards a brown red, and fuses finally into a liquid of the same colour, which sets, on cooling, in a mass of a clear yellow colour. Iodide of lead combines with hydrochloric acid, the iodides of potassium, ammonium, &c., forming double salts; with ammonia it forms an iodide, the symbol of which is $[\text{Pb}\,H_6\,N_2]\,I_2$.

Combinations of Lead with the Diatomic Metalloids.—Sulphuret of Lead, $\text{Pb}\,S$.—Sulphuret of lead is found in a natural state. It forms the most abundant lead ore, and is known in commerce as galena. It may be obtained artificially by acting upon the solution of a soluble salt of lead with hydrosulphuric acid.

$$\underset{\text{Neutral nitrate of lead.}}{\text{Pb}\left\{\begin{matrix}\Theta N \Theta_2\\ \Theta N \Theta_2\end{matrix}\right.} + \underset{\text{Hydrosulphuric acid.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}S} = \underset{\text{Nitric acid.}}{2\left(\left.\begin{matrix}N\Theta_2\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Sulphuret of lead.}}{\text{Pb}\,S}$$

Sulphuret of lead, prepared by a double decomposition, constitutes a black and amorphous powder. Galena, on the contrary, crystallizes in the cubic form. Its crystals are of a bluish grey colour, and possess a metallic lustre. Its specific gravity is from 7·25 to 7·7; at a red heat it fuses, and may even become slightly volatilized.

We have already seen that when galena is roasted, there are formed sulphureous anhydride, oxide, and sulphate of lead; and also that when heated while unexposed to the air with the oxide or the sulphate, galena gives sulphureous anhydride and metallic lead. Hydrochloric acid has no effect upon galena, nor has dilute sulphuric acid; but this latter acid when concentrated gives up oxygen to the galena, which passes into the state of sulphate, and reduces itself to water and sulphureous anhydride. Dilute nitric acid transforms galena into nitrate of lead with a deposit of sulphur; this sulphur comes from the hydrosulphuric acid which is formed at first, and which the nitric acid afterwards decomposes.

$$\underset{\text{Sulphuret of lead.}}{\text{Pb}\,S} + \underset{\text{Nitric acid.}}{2\left(\left.\begin{matrix}N\Theta_2\\H\end{matrix}\right\}\Theta\right)} = \underset{\text{Nitrate of lead.}}{\text{Pb}\left\{\begin{matrix}\Theta N \Theta_2\\ \Theta N \Theta_2\end{matrix}\right.} + \underset{\text{Hydrosulphuric acid.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}S}$$

If the nitric acid is concentrated, a portion of the sulphur deposited becomes oxidized at its expense, sulphuric acid is produced, and this acid precipitates an equivalent quantity of lead as an insoluble sulphate. Thus the same products are obtained as with the dilute acid, and the sulphate of lead in addition. If the acid is at its greatest concentration, the whole of the sulphur passes into the state of sulphuric acid, and consequently only sulphate of lead is obtained.

Galena is often argentiferous; the richest specimens are those which crystallize in little crystals. Along with the sulphuret of lead, $\text{Pb}\,S$, there appears to exist a hemi-sulphuret of this metal, $\text{Pb}_2\,S$, and a tetarto-sulphuret, $\text{Pb}_4\,S$. The hemi-sulphuret is formed during the metallurgical treatment of galena. It may also be prepared by fusing two atoms of lead with one of sulphur. The tetarto-sulphuret is obtained by calcining 100 parts of galena with 84 of lead.

Protoxide of Lead, $\text{Pb}\,\Theta$.—When lead is heated while exposed to the air, a yellow powder is formed, known by the name of *massicot*, which is nothing but protoxide of lead. Massicot is formed also when carbonate or nitrate of lead is subjected to a certain degree of calcination. Massicot when cooling from a state of fusion, crystallizes, and is then known as *litharge*.

Oxide of lead assumes various shades of colour. If, for example, litharge be heated, it changes from a reddish to a light yellow, and goes back to its original colour as it cools. Litharge decomposes the alkaline salts, liberating caustic alkali; but to do this the plumbic oxide must be in excess. When boiled with a very concentrated solution of potassa litharge dissolves, but is again deposited in very heavy little crystals by the cooling of the liquor.

The protoxide of lead when fused and raised to a red heat absorbs oxygen, but gives it up again as it cools, like metallic silver. When heated in an earthen crucible, it combines with the silicate of the crucible, forming a fusible silicate, and the crucible is quickly burned through. Protoxide of lead produces the double decomposition with the acids, and gives very stable salts of lead. It is therefore a basic anhydride. We have already observed that it may be dissolved in the alkaline liquors, and that it may sometimes act as an acid anhydride. Its basic properties, however, are far more important than its acid properties. When protoxide of lead is heated for a long time while exposed to the air, red-lead is formed.

Plumbic Hydrate, $\text{Pb}\left\{\begin{matrix}\Theta H\\ \Theta H\end{matrix}\right.$.—This hydrate is not known, but there exist a great number of salts corresponding to it, the most important of which are, the sulphate, the nitrate, the chromate, the acetate, and the carbonate.

Sulphate of Lead, $\left.\begin{matrix}S\Theta_2\\ \text{Pb}\end{matrix}\right\}\Theta_2$.—For printing purposes, acetate of aluminium is prepared by precipitating the sulphate of alumina by the acetate of lead; sulphate of lead is formed in this reaction as an accessory product.

$$\underset{\text{Aluminic sulphate.}}{\left.\begin{matrix}(S\Theta_2)^3\\ Al_2\end{matrix}\right\}\Theta_6} + \underset{\text{Acetate of lead.}}{3\left(\text{Pb}\left\{\begin{matrix}\Theta\,C_2H_3\Theta\\ \Theta\,C_2H_3\Theta\end{matrix}\right.\right)} = \underset{\text{Acetate of alumina.}}{\left.\begin{matrix}Al_2\\ (C_2H_3\Theta)^6\end{matrix}\right\}\Theta_6} + \underset{\text{Sulphate of lead.}}{3\left(\left.\begin{matrix}S\Theta_2\\ \text{Pb}\end{matrix}\right\}\Theta_2\right)}$$

The sulphate of lead is a white powder, insoluble in water, and partially soluble in the acid liquors. The ammoniacal salts dissolve it by causing with it the double decomposition, that is,

by decomposing it. Of all these salts, tartrate of ammonium dissolves sulphate of lead best. The sulphate of lead is not decomposable by heat alone, a quality that clearly distinguishes it from the sulphates of all the other common metals. Iron, zinc, and carbon reduce it. With carbon, according to the proportions in which the two substances are mixed, and the rapidity with which they are heated, the sulphate of lead is converted into sulphuret or subsulphuret of lead, or even into metallic lead; in the two latter cases, sulphureous anhydride is evolved. When boiled with a solution of carbonate of soda, the sulphate is converted into carbonate of lead, whilst the sodium passes into the state of a sulphate If a wetted compound of one molecule of sulphate of lead and hal a molecule of lime be left, hydrate of lead will be formed, which may be converted into acetate by dissolving it in acetic acid. These are so many means of utilizing sulphate of lead, which is considered in workshops as of no value.

Nitrate of Lead, $Pb\left\{\begin{matrix}\Theta N \Theta_2\\ \Theta N \Theta_2\end{matrix}\right.$.—This nitrate is prepared by dissolving oxide of lead, or metallic lead in boiling nitric acid. As this salt is not very soluble in the acids, it is precipitated as it is formed. It is dissolved in water and then crystallized. Nitrate of lead dissolves much better in hot than in cold water. Alcohol does not dissolve it. Heat decomposes it into oxygen, hyponitride, and oxide of lead. When boiled with oxide of lead, it is converted into a basic salt corresponding to the formula $Pb\left\{\begin{matrix}\Theta N \Theta_2\\ \Theta H\end{matrix}\right.$.

$$\underset{\text{Neutral nitrate of lead.}}{Pb\left\{\begin{matrix}\Theta N \Theta_2\\ \Theta N \Theta_2\end{matrix}\right.} + \underset{\text{Oxide of lead.}}{Pb\Theta} + \underset{\text{Water.}}{\left.\begin{matrix}H\\ H\end{matrix}\right\}\Theta} = \underset{\text{Basic nitrate of lead.}}{2\left(Pb\left\{\begin{matrix}\Theta N \Theta_2\\ \Theta H\end{matrix}\right.\right)}$$

When heated with metallic lead and water, it is converted into nitrite with a great excess of metal. If this nitrite is subjected to the action of a current of carbonic anhydride, it gives carbonate and neutral nitrite of lead.

$$1.\quad \underset{\text{Neutral nitrate of lead.}}{Pb\left\{\begin{matrix}\Theta N \Theta_2\\ \Theta N \Theta_2\end{matrix}\right.} + \underset{\text{Lead.}}{2Pb} = \underset{\text{Triplumbic nitrite.}}{\left.\begin{matrix}Pb\{\Theta N\Theta\\ Pb\{\Theta\\ \quad\ \Theta\\ Pb\{\Theta N\Theta\end{matrix}\right\}}$$

$$2.\quad \underset{\text{Triplumbic nitrite.}}{\left.\begin{matrix}Pb\{\Theta N\Theta\\ Pb\{\Theta\\ \quad\ \Theta\\ Pb\{\Theta N\Theta\end{matrix}\right\}} + \underset{\text{Carbonic anhydride.}}{2\bar{C}\Theta_2} = \underset{\text{Carbonate of lead.}}{2\left(\left.\begin{matrix}\bar{C}\Theta\\ Pb\end{matrix}\right\}\Theta_2\right)} + \underset{\text{Neutral nitrite of lead.}}{Pb\left\{\begin{matrix}\Theta N\Theta\\ \Theta N\Theta\end{matrix}\right.}$$

Chromate of Lead, $\left.\begin{matrix}\bar{Cr}\Theta_2\\ Pb\end{matrix}\right\}\Theta_2$.—Chromate of lead is prepared by double decomposition by means of acetate of lead and potassic chromate or dichromate.

$$\underset{\text{Chromate of potassa.}}{\left.\begin{matrix}\bar{Cr}\Theta_2\\ K_2\end{matrix}\right\}\Theta_2} + \underset{\text{Acetate of lead.}}{Pb\left\{\begin{matrix}\Theta \bar{C}_2H_3\Theta\\ \Theta \bar{C}_2H_3\Theta\end{matrix}\right.} = \underset{\text{Chromate of lead.}}{\left.\begin{matrix}\bar{Cr}\Theta_2\\ Pb\end{matrix}\right\}\Theta_2} + \underset{\text{Acetate of potassa.}}{2\left(\left.\begin{matrix}\bar{C}_2H_3\Theta\\ K\end{matrix}\right\}\Theta\right)}$$

Chromate of lead is also found native in the form of a red substance, crystallized in oblique rhomboidal prisms, the red-lead of mineralogists.

The artificial chromate is of a bright yellow colour; it is used as a pigment under the name of chrome yellow. When raised to a red heat it fuses, and sets, on cooling, in a reddish mass. If, instead of precipitating the neutral chromate of potassa by the neutral acetate of lead, liquors not neutral are precipitated, the precipitate has a variable colour. The colours may also be made to vary with the temperature at which the precipitation is effected. Generally the chromates of lead are charged with metal in proportion to their redness.

Neutral Acetate of Lead, $Pb\left\{\begin{matrix}\Theta \bar{C}_2H_3\Theta\\ \Theta \bar{C}_2H_3\Theta\end{matrix}\right. + 3$ aq.—When lead is left to the simultaneous action of the air and the vapours of acetic acid, a basic acetate of lead is formed. Dissolved in an excess of acetic acid, this acetate gives a liquor which, when evaporated, leaves a deposit of beautiful crystals, the formula of which is $Pb\left\{\begin{matrix}\Theta \bar{C}_2H_3\Theta\\ \Theta \bar{C}_2H_3\Theta\end{matrix}\right. + 3$ aq. The same salt may be obtained by dissolving litharge in acetic acid. The neutral acetate of lead is extremely soluble in water. Ammonia does not precipitate it, because this alkali gives with the plumbic salts, not hydrate, but sub-salts of lead, and the sub-salts of lead are soluble. Neutral acetate of lead in aqueous solution when hot readily dissolves litharge. There is formed, in this case, either a simple bibasic salt, or polyplumbic salts. All these salts, when subjected to the action of a current of carbonic anhydride, give a precipitate of carbonate of lead, whilst the neutral acetate of the same metal regenerates itself.

$$\underset{\text{Neutral acetate of lead.}}{Pb\left\{\begin{matrix}\Theta \bar{C}_2H_3\Theta\\ \Theta \bar{C}_2H_3\Theta\end{matrix}\right.} + \underset{\text{Oxide of lead.}}{Pb\Theta} + \underset{\text{Water.}}{H_2\Theta} = \underset{\text{Bibasic acetate of lead.}}{2\left(Pb\left\{\begin{matrix}\Theta \bar{C}_2H_3\Theta\\ \Theta H\end{matrix}\right.\right)}$$

$$\underset{\text{Bibasic sub-acetate of lead.}}{2\left(Pb\left\{\begin{matrix}\Theta \bar{C}_2H_3\Theta\\ \Theta H\end{matrix}\right.\right)} + \underset{\text{Carbonic anhydride.}}{\bar{C}\Theta_2} = \underset{\text{Carbonate of lead.}}{\left.\begin{matrix}\bar{C}\Theta\\ Pb\end{matrix}\right\}\Theta_2} + \underset{\text{Neutral acetate of lead.}}{Pb\left\{\begin{matrix}\Theta \bar{C}_2H_3\Theta\\ \Theta \bar{C}_2H_3\Theta\end{matrix}\right.} + \underset{\text{Water.}}{H_2\Theta}$$

Neutral Carbonate of Lead, $\left.\begin{matrix}CO\\Pb\end{matrix}\right\}O_2$.—Carbonate of lead is found native in crystals of the fourth order. In laboratories this substance is obtained in the form of a white pulverulent powder by precipitating a solution of carbonate of soda by a solution of acetate of lead.

Carbonate of lead (white-lead), being much used as a pigment, is prepared on a large scale. It is prepared for industrial purposes by two processes—one founded on an old method, known as the Dutch process; the other, modern, discovered by Thénard, and known as the Clichy process.

In the Dutch method, vessels filled with vinegar, in which strips of lead rolled into spirals are suspended, are placed in a dung-heap in course of fermentation at a temperature of 95° to 100°. These vessels are rudely closed with a piece of sheet lead. The strips of lead are thus subjected to the simultaneous action of the air, the vapours of acetic acid, and the carbonic anhydride which is produced in the fermentation of the dung. Under the influence of the air and the vinegar the lead becomes at first covered with basic acetate, which, in contact with the carbonic anhydride, regenerates neutral acetate, and gives carbonate of lead. From time to time the film of carbonate adherent to the strips of metal is removed, and this salt washed, to rid it of the acetate which it contains. It is afterwards dried and pulverized.

In the Clichy process, a sufficient quantity of litharge is dissolved in acetic acid to obtain the triplumbic acetate.

$$\left.\begin{matrix}Pb\{O\,C_2H_3O\\Pb\left\{\begin{matrix}O\\O\end{matrix}\right.\\Pb\{O\,C_2H_3O\end{matrix}\right\} + 3\,aq.$$

The solution of this salt is then subjected to the action of a current of carbonic anhydride, two molecules of oxide of lead separate in the state of carbonate, and the neutral acetate is regenerated.

$$\underset{\text{Triplumbic acetate.}}{\left.\begin{matrix}Pb\{O\,C_2H_3O\\Pb\left\{\begin{matrix}O\\O\end{matrix}\right.\\Pb\{O\,C_2H_3O\end{matrix}\right\}} + \underset{\text{Carbonic anhydride.}}{2\,CO_2} = \underset{\text{Carbonate of lead.}}{2\left(\left.\begin{matrix}CO\\Pb\end{matrix}\right\}O_2\right)} + \underset{\text{Neutral acetate of lead.}}{Pb\left\{\begin{matrix}O\,C_2H_3O\\O\,C_2H_3O\end{matrix}\right.}$$

The regenerated neutral acetate, when boiled with litharge, furnishes a fresh quantity of triplumbic acetate, which is again brought into the state of neutral carbonate, so that, with the exception of inevitable waste, the same quantity of acetic acid will serve for an indefinite time.

White-lead obtained by this process is inferior in quality to that prepared by the Dutch method, on account of its being composed of crystalline and transparent particles, but its quality may be rendered equal to that of the other kind by boiling it with a small quantity of carbonate of potassa.

Carbonate of lead is decomposed by the influence of heat into oxide of lead and carbonic anhydride.

$$\underset{\text{Carbonate of lead.}}{\left.\begin{matrix}CO\\Pb\end{matrix}\right\}O_2} = \underset{\text{Carbonic anhydride.}}{CO_2} + \underset{\text{Oxide of lead.}}{PbO}$$

It dissolves in the acids, and gives off carbonic anhydride; at the same time water and a salt of lead are produced.

$$\underset{\text{Carbonate of lead.}}{\left.\begin{matrix}CO\\Pb\end{matrix}\right\}O_2} + \underset{\text{Nitric acid.}}{2\left(\left.\begin{matrix}NO_2\\H\end{matrix}\right\}O\right)} = \underset{\text{Carbonic anhydride.}}{CO_2} + \underset{\text{Nitrate of lead.}}{Pb\left\{\begin{matrix}ONO_2\\ONO_2\end{matrix}\right.} + \underset{\text{Water.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}O}$$

Sulphuretted hydrogen blackens it, in common with all the other salts of lead, by forming a sulphuret of lead; this renders colours containing it changeable. It has been proposed to restore the original colours of paintings blackened by sulphuretted hydrogen by subjecting the painting to the action of oxygenated water. The sulphuret of lead is thus changed into a sulphate, which is white, like white-lead, and the colour is in this way restored.

Diplumbic Hydrate, $\left.\begin{matrix}Pb\left\{\begin{matrix}OH\\O\end{matrix}\right.\\Pb\{OH\end{matrix}\right\}$.—This substance is obtained by precipitating a soluble salt of lead by potassa. The hydrate of lead is soluble in $\frac{1}{7000}$ of its weight of water; the alkalies in excess dissolve it readily. It is white in colour; when heated it loses water, and is converted into a reddish anhydrous protoxide.

Binoxide of Lead (Plumbic Anhydride), PbO_2.—Red-lead, as we shall presently see, may be considered as a plumbate of lead. When acted upon by the acids, it gives up to them the elements of the protoxide of lead, and there remains a puce-coloured powder, which, when washed and dried, constitutes plumbic anhydride, PbO_2. This substance may also be obtained by acting upon the protoxide of lead, in suspension in water, with hypochlorous acid.

The binoxide of lead is an acid anhydride; it combines with the bases and gives crystallized salts. Frémy obtained, by heating this substance with potassic hydrate, a crystallized plumbate of potassa, to which he has applied the formula $PbO_2, K_2O + 3$ aq., but which might be written in a more rational manner $\left.\begin{matrix}Pb\\K_2\\H_2\end{matrix}\right\}O_4 + 2$ aq., thus referring it to the type of the normal plumbic acid

$\left.\begin{matrix}\mathrm{Pb}\\ \mathrm{H}_4\end{matrix}\right\}\Theta_4$. When heated with an acid, plumbic anhydride loses oxygen, and is converted into a salt of lead; hence it follows that a compound of plumbic anhydride and sulphuric acid is a powerful oxidizing agent.

$$\underset{\text{Plumbic anhydride.}}{2\,\mathrm{Pb}\Theta_2} + \underset{\text{Sulphuric acid.}}{2\left(\left.\begin{matrix}\mathrm{S}\Theta_2\\ \mathrm{H}_2\end{matrix}\right\}\Theta_2\right)} = \underset{\text{Sulphate of lead.}}{2\left(\left.\begin{matrix}\mathrm{S}\Theta_2\\ \mathrm{Pb}\end{matrix}\right\}\Theta_2\right)} + \underset{\text{Water.}}{2\left(\left.\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\Theta\right)} + \underset{\text{Oxygen.}}{\left.\begin{matrix}\Theta\\ \Theta\end{matrix}\right\}}$$

Red-Lead, or Saline Oxide, $\mathrm{Pb}_3\Theta_4$.—This oxide may be regarded as a salt derived from the normal plumbic acid by the substitution of Pb_2 for H_4.

$$\underset{\text{Plumbic acid.}}{\left.\begin{matrix}\mathrm{Pb}\\ \mathrm{H}_4\end{matrix}\right\}\Theta_4} + \underset{\text{Hydrogen.}}{2\left(\left.\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\right)} + \underset{\text{Lead.}}{2\,\mathrm{Pb}} = \underset{\text{Plumbate of lead (red-lead).}}{\left.\begin{matrix}\mathrm{Pb}\\ \mathrm{Pb}_2\end{matrix}\right\}\Theta_4}$$

Red-lead may indeed be prepared by mixing potassic solutions of plumbic anhydride and protoxide of lead; the red-lead will be precipitated in the hydrated state. For industrial purposes, red-lead is obtained by the simultaneous action of the air and heat upon the protoxide. So prepared, it does not offer a constant composition.

Distinctive Characters of the Salts of Lead.—The soluble salts of lead may be known by the following characteristics;—

1. Hydrochloric acid produces with them a white precipitate. This precipitate is insoluble in ammonia, which does not change the colour of it. It dissolves in boiling water, and is deposited in crystalline spangles on the cooling of the liquor.

2. Hydrosulphuric acid determines with them the formation of a black precipitate of sulphurate of lead, insoluble in the sulphurate of ammonium, and capable of being acted upon by boiling nitric acid, which converts it partly into a soluble nitrate and partly into an insoluble sulphate.

3. Sulphuric acid precipitates these salts white. The precipitate is soluble in tartrate of ammonia.

4. The soluble chromates give with the salts of lead a yellow precipitate soluble in potash.

5. The fixed alkalies give with them a white precipitate soluble in an excess of the reagent.

The best-known ores of lead are the sulphurets, carbonates, phosphates, arseniates, and sulphates; but we shall restrict our observations to the first named, as the quantity obtained from the others is commercially unimportant.

Galena or sulphuret of lead may be considered the matrix of all other lead ores; where they exist we are sure to find galena. It is always crystallized, however minute the crystals may be: the form of the crystals is a cube composed of rectangular plates. The colour of the ore is grey, similar to that of the polished metal, which it also resembles in lustre. It forms a grey metallic powder when rubbed. Its specific gravity is 7·3 to 7·7. Galena consists of 86·66 lead, and 13·34 sulphur. The ore contains also, at times, selenium, zinc, silver, copper, antimony, and other metals. Silver is the most valuable of these admixtures, and is generally extracted from the metal. German galena contains from ·03 to ·05 per cent. of silver; the English, ·02 to ·14; Swedish, ·76; the ore at Monroe, Ct., 3 per cent.; Eaton, N. H., ·1 per cent.; and that from the State of Arkansas may contain from ·003 to ·05 per cent. Galena occurs in beds and veins, both in crystalline and stratified rock, particularly in the carboniferous or mountain limestone. It is often associated with blende, iron ore, copper pyrites, and a variety of other lead ores. It occurs in gangue of heavy spar, calc spar, quartz, and other substances. Extensive deposits of it exist in the United States. The lead ores of Missouri extend over 3000 square miles. From the Mississippi River, about 60 miles above St. Louis, they extend 70 miles in length and 45 miles in width, over a sterile, rolling country, a highland prairie. The soil is reddish, coloured by iron, with clay, full of flint and quartz pebbles, to the depth of 10 or 20 ft. The lead region of Wisconsin is equally extensive as that of Missouri, if not more so; it comprises about 5000 square miles, extending into Iowa and Illinois. Galena is not free from foreign metals, of which silver is always present. This ore is therefore not only an accidental silver ore, but it may be considered argentiferous in all its varieties. The amount of silver in lead ore is easily ascertained by an assay, and ought to be thus determined when it is doubtful. As a general rule, the purest kinds of galena contain the least silver. The ores of the secondary and younger formation, particularly the ore of the limestone of that period, are always poor in silver. All deposits of galena which occur in heavy masses are also poor in silver. Galena which in small veins ramifies a stratified rock is generally rich in silver, and the smallest branches and forks are richest. The heaviest deposits of galena occur in limestone rock. The dimensions of a vein diminish as it penetrates sandstone strata, and grow still smaller in traversing shale or slate. In these rocks the metal is frequently replaced by clay or fragments of rock, and the vein does not show any ore.

Alloys of Lead.—A very extensive use of the alloys of lead is made in type metal. Nine lead and 1 antimony form common type metal; 7 lead and 1 antimony are used for large and soft type; 6 lead and 1 antimony for large type; 5 lead and 1 antimony for middle type; 4 lead and 1 antimony for small type; and 3 lead and 1 antimony for the smallest kinds of type. Type metal frequently contains tin, copper, bismuth, and other metals. Stereotype metal is generally lead alloyed with antimony in the rates of 4 to 8 of the former to 1 of the latter; to this are always added some bismuth, tin, and frequently a little copper. Soft solder varies from 66 lead to 33 lead in 100 parts, the rest is tin. A small amount of bismuth renders lead tougher; equal parts of each and bismuth form a brittle alloy. Lead and tin melt together in all proportions, forming a harder and tougher metal than either alone. A small addition of lead to brass causes the latter to be tougher and more suitable for use in the machine shop. Lead has a strong affinity for carbon; oxide of

lead mixed with fine carbon, and heated in a covered crucible, forms a black carburet of lead. Lead unites with potassium or sodium like antimony, but does not absorb so large quantities of the alkaline metals as the latter. Arsenic has a strong affinity for lead, and combines with it on covering melted lead with arsenious acid; arsenic-lead and oxide of lead are thus formed. This alloy, 98 lead and 2 arsenic, is used for making shot, by dropping the fused metal from a high elevation in a shot-tower into a basin of water; or throwing the fluid metal down a stack of limited height, in which a strong draught of air is produced by a blast machine. Mercury amalgamates very readily with lead. A rod of lead, bent in the form of a siphon, will transfer mercury from one vessel to another in the same manner as lamp-wick conducts oil. An amalgam of lead crystallizes similar to that of gold, from which the superfluous mercury may be separated by pressing it through buckskin. Copper and lead do not combine very readily, they require a white heat for union. The alloy thus formed, under the influence of a high heat, must be suddenly cooled, or both metals will separate in cooling. Lead may be separated from copper by liquation, as practised in refining tin; but all the lead cannot be removed by these means; a small quantity always adheres tenaciously to copper. This alloy is brittle; a little lead is injurious to copper. Organ pipes consist of lead alloyed with tin, about half and half. This alloy is cast, instead of rolled, in the desired form of sheets, in order to obtain a crystallized metal, which produces a finer tone. The sheets are formed in casting the metal on a horizontal table, the thickness is regulated by the height of a rib, or bridge, at one end, over which the superfluous metal flows off. The rough sheets thus obtained are planed by means of a carpenter's plane, bent up, and soldered.

Manufacture of Lead.—Although lead may readily be revived from its ores by applying a moderate heat and by simple means, yet, to obtain as much metal as possible at the least cost, has given rise to a variety of forms in furnaces and methods in the treatment of ores. Galena is reduced simply by melting it in a black pot. If a backwoodsman wants shot or bullets, he will kindle a fire in a hollow tree or an old stump of a tree, place some galena on the charred wood and melt it down. After cooling, he finds the metal at the bottom of the hollow. Formerly lead was smelted in log furnaces, in Missouri—a rude kind of square furnace, constructed of logs or stones.

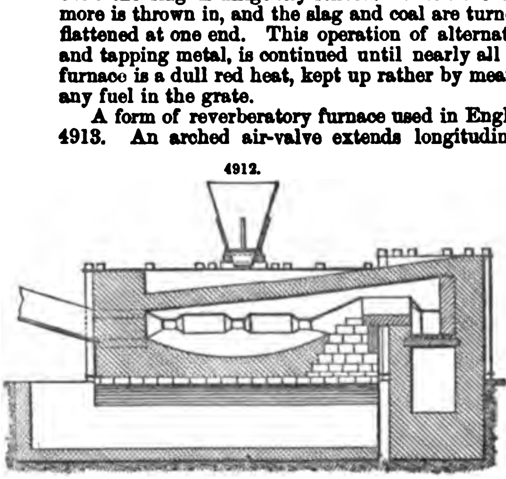
In the system of smelting lead ores there is more variety than in any other class of smelting operations. The ore is roasted, crushed, and washed, preparatory to smelting, and these preparations are attended to with greatest care in Europe. We shall describe a few methods, and allude to such apparatus and operations only as are approved of at the present time.

An ordinary method of smelting lead is to pick the ore well by hand and remove gangue, which consists chiefly of heavy spar and quartz, and then smelt it in reverberatory or blast furnaces. The rich slags obtained by these processes are once more subjected to smelting in a slag furnace. There is not much difference in the form of the reverberatory furnaces for smelting lead or other metals. The furnace hearth for smelting lead is about 8 ft. long and 6 ft. wide; the hearth is 24 or 26 in. above the bottom. There are two or three small work doors on each side of the furnace, beside the tap-hole for the metal, and one for the scoria. The hearth is formed of poor refractory slags, firmly rammed down to form a basin towards the tap-side. From this side the metal is run into an iron kettle, from which it is ladled into moulds. In the middle of the roof there is an aperture for charging the ore into the furnace.

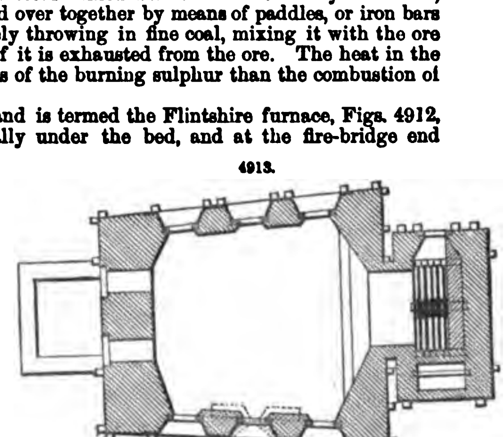
When the furnace is heated and charged with about a ton of ore, a gentle heat is applied for the first couple of hours. All the doors are closed during this interval, and the register at the chimney is lowered. During this process of sweating, some metal is separated, and gathers in the basin of the furnace. When the ore is thus uniformly heated, some fine charcoal is thrown into the furnace, and mixed with the slag. The metal thus formed is tapped off, the heat raised, and then the slag is diligently stirred. When the charcoal mixed with the ore is nearly consumed, more is thrown in, and the slag and coal are turned over together by means of paddles, or iron bars flattened at one end. This operation of alternately throwing in fine coal, mixing it with the ore and tapping metal, is continued until nearly all of it is exhausted from the ore. The heat in the furnace is a dull red heat, kept up rather by means of the burning sulphur than the combustion of any fuel in the grate.

A form of reverberatory furnace used in England is termed the Flintshire furnace, Figs. 4912, 4913. An arched air-valve extends longitudinally under the bed, and at the fire-bridge end

4912.



4913.



it communicates with the external air. On the crown of this arch, extending right and left, a level course of brickwork, called the cramp-course, is laid; and on this are placed iron cramps, which hold the lower ends of vertical wrought-iron standards. Upon the cramp-course a concave bed of common brickwork, grouted with lime mortar, is raised solid, sloping from the back as well

as from each end to the tap-hole in front, the bricks being set gradually back in each successive course. At the front and back are openings at equal distances, and of the same dimensions. These openings are formed by strong cast-iron door-frames, bevelled off at the top towards the interior of the furnace and at the bottoms, that the frames may stand firmly, with a slight inclination inwards. In front of both series of door-frames, and on a level with the bottom of the openings in these frames, extends a cast-iron plate about 10 ft. long, 7 in. wide, and 2 in. thick, set flatwise and horizontally. On the bevelled tops of each series of door-frames rests inclined a strong flat plate of cast iron, to support the roof of the furnace on each side. In front of each series of door-frames, plates or jambs of cast iron, about ¾ in. thick, are placed vertically. There are four castings for each series, those at the ends, right and left, being different from those on each side of the middle door. On the sloping edges of these jambs at the top rests inclined the cast-iron plate above mentioned; thus each door-frame is recessed. At the front of the furnace, below the middle door-frame, is a large plate of cast iron, called the tap-hole plate, strengthened by a longitudinal projecting rib at the top and bottom. In the middle of the tap-hole plate is a narrow vertical opening, fitted with a hinged door, and below the bottom of this door is the tap-hole. Immediately under the tap-hole plate, and facing the tap-hole, is a pot of cast iron, much thicker at the bottom, called the lead-pot, lead-pan, or lead-kettle, and contiguous to the tap-hole is a notch. The bed is covered in above with a low flat arch firmly supported on either side, and extending from the end wall of the fire-place to the opposite or flue end of the furnace. Immediately above a line drawn from the middle of the door-frame nearest the fire-place at the front to the middle of the opposite door-frame at the back, the arch presents a very obtuse angle, upon the importance of which, says Percy, stress is laid by the builders of these furnaces. From the middle of this line to the lower surface of the arch vertically above the distance should be 17 in.; from the middle of a line drawn from the door-frame nearest the flue to the opposite door-frame the distance to the top of the arch vertically above should be 13 in.; and from the middle of the top of the fire-bridge to the top of the arch vertically above it the distance should be 19 in. In the roof facing the middle door-frames, but nearest that at the front, is an opening through which the furnace is charged from a bin or hopper above. The fire-hole for charging coal is at the back, and the grate is freed from clinker or cleaned at front. Above and in front of the ash-pit at the front is a short flue for carrying off any vapour that may proceed therefrom. An open space is left for the free circulation of air between the inner fire-place wall and the adjacent end wall of the bed. The upper part of the latter wall under the fire-bridge is supported by a strong cast-iron plate, called as usual the bridge-plate. At the opposite end of the furnace are two rectangular flues, that nearest the back larger than the other. The object of this difference is, it is stated, to cause more flame to pass over the higher part of the bed contiguous to the larger flue. Both openings communicate with a common flue connected with a high stack; and that flue is provided with a damper, of which much use is made when the furnace is in operation. At the flue end on the outside there are recessed openings, corresponding to the two flues, through which access to them may be gained. They are closed with fire-brick. The lead-pot is firmly held in its place by a wrought-iron hoop. The space over the roof between the surrounding vertical walls is more or less fitted with ashes or sand to lessen loss of heat by radiation.

The working bottom of the furnace is usually made of the grey slag supplied by the furnace itself. The slag having been broken up in pieces of about the same size, road metal is thrown into the furnace, previously made red hot, spread over the brick foundation, and then melted. When liquid it runs into the lower part or well of the furnace, where it is allowed to cool until it becomes pasty, in which state it is spread by rakes over the brick foundation, worked into the desired shape, and afterwards left to solidify by cooling.

The usual charge for a furnace is 21 cwt. of ore, with draughtage calculated to cover the moisture in the ore. The furnace being barely red hot, after working off the previous charge the ore is let fall from the hopper or bin through the hole in the arch underneath, spread pretty evenly over the bed, care being taken to prevent any of it from dropping into the deepest part or well of the furnace, and frequently stirred and turned over for two hours. During this operation the temperature in the furnace is regulated by the damper, and the doors are left open or only partially closed in order to admit the requisite quantity of air. Constant stirring and the highest temperature compatible with the absence of pastiness or clotting are the essential conditions of this stage. At the end of the two hours the grate is freed from clinkers and filled with coal, and the fire urged until the charge becomes semi-liquid, and any portion of it which may not have run towards the tap-hole is raked up to that which remained on the upper part of the furnace bed. The fire-door is now opened and the temperature lowered until the charge acquires the consistency of stiff paste, when the whole of it is pushed towards the bridge. The fire-door is then closed, and the charge melted down as quickly as possible into the well; slaked lime in powder is thrown in and raked over the surface of the melted mass. The slag and unreduced portion of ore being thus rendered sufficiently stiff, are again set-up on the sloping sides of the bed, there left to cool a little, and afterwards remelted. Lime again added, the slag is pushed back from the surface of the lead and left to drain a little, the lead tapped, and the slag is then raked out of the furnace in pasty lumps, termed grey slag.

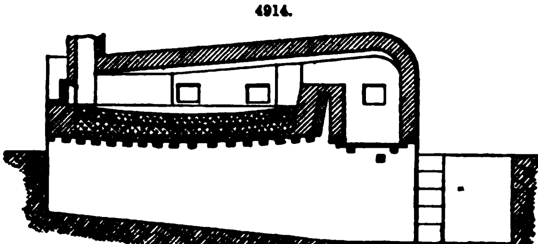
In Germany generally the ores are purified by hand; washed, stamped, and washed again, and roasted with salt, or iron, or iron ore.

The roasted ore is smelted in blast furnaces, which are from 12 to 14 ft. high. The front or tymp of the furnace is walled up with bricks, which are temporarily put in with clay mortar. The width of the furnace is from 12 to 14 in. square or oblong. The hearth, or bottom of the furnace, is formed of a mixture of loam and charcoal dust firmly rammed in. The basin outside of the tymp contains the lead, which is tapped off by opening a tap-hole communicating with its bottom. The slags are conducted on a slope to a basin wherein they are accumulated for re-smelting.

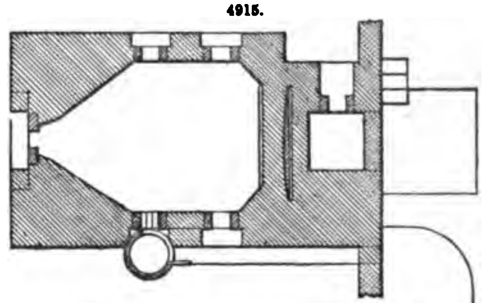
This furnace may be fed either by charcoal or coke; the latter requires a blast somewhat stronger than the former, but in no case more than ½ or ⅜ lb. pressure. A fan-blower is sufficient for charcoal; coke requires a cylinder blast. Coke operates as well as charcoal, and yields equally as much and as good metal from the ore as the latter. In working the furnace it is warmed previously to charging ore, which is mixed with fluxes, such as litharge, iron ore, calc spar, fluor spar, or other substances. Fuel and ore are charged alternately, as at any other blast furnace. The blast is gently urged in case charcoal is the fuel. The metal, or metals, gather below the tuyere in the basin of the hearth, and separate into various strata; pure lead and all the silver is at the bottom; upon this there is a stratum of alloys of lead and other metals, and on the top a stratum of matt which is covered by the poor silicious slags. The latter may be carefully drawn off and removed without drawing any matt or metal. When the matt reaches so high as to admit very little slag on its surface the blast is stopped, the tuyere temporarily closed up, and the metal tapped into the basin. As the purest metal is below the matt, and the furnace tapped at the bottom, this flows out first; and when the drawing is not hurried, it may in some measure be separated from the impure metal and the matt on its top. Generally the metal is tapped from the furnace at intervals of eight hours, and very little is left in the furnace. When it is thus removed, the hearth is cleared of adhering cinder by opening the tymp, and the operation goes on as before. A continual blast of six days and nights' work may thus be made, after which the furnace is cooled and thoroughly repaired. In the basin before the hearth, into which the metal has been tapped, and which is kept well heated, the metals separate again into different strata, which may be obtained after removing the cold crust of slags as it forms on the surface. As the purest lead is at the bottom of the basin, it is ladled out after the upper strata of alloy and matt have been removed. In this operation the poor slags are thrown away, and the rich ones and matt are re-smelted with the ore.

The best and purest kind of lead is smelted in a modification of the Flintshire reverberatory furnace, known as the flowing furnace, Figs. 4914, 4915. Its chief points of difference are that it

4914.



4915.



has a smaller number of working openings. The bottom is carried on bars of iron, and there is a small pit at the side arranged for the overflow of the regulus from the lead-pot. The furnace is usually lined with fire-brick cased with granite, and has the working bottom lined with slag. The hearth is very much sloped towards the small pits *a*.

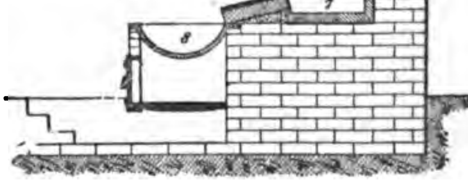
The operation in this furnace is similar to that for other reverberatories. The ore is successively sweated, roasted, and reduced. The slags which remain after that operation are reduced in the blast furnace. In front of the furnace, as we have stated before, is a cast-iron pan, or kettle, into which the lead is tapped, and from which it is ladled into the pig moulds. In these pans very large crystals of lead may be obtained, when the metal is suffered to cool slowly.

At the Hartz Mountains, in Northern Germany, galena is reduced by the assistance of iron in blast or elbow furnaces; see Fig. 3089. When constructed for using coke, these furnaces are very low, or not more than 3 or 4 ft. high; for charcoal they are from 18 to 20 ft. high.

The ore which is smelted in these furnaces is always extremely well prepared, pounded, and washed. Instead of iron ore, granulated cast iron is used with success. The ores may be very impure, but the lead is always obtained in great purity.

English Ore-hearth.—Fig. 4916 is a vertical section of the ore hearth from front to back. The hearth consists of twelve pieces of cast iron.

4916.



3 is the hearth bottom, measuring in the North of England 22 in. square; the bottom 3 in. thick, and the sides 3 in. by 4½ in.; it is open in front. Between the hearth bottom and the bed on which it rests is interposed a layer of sand a few inches thick. The work-stone slopes 3 in. from the front edge of the hearth bottom; it is 3 ft. long, 1½ in. broad, and 2½ in. thick, having a raised border 1 in. high on its two sides and in front, with a channel 2 in. wide and 7 in. deep running diagonally across it. The space between the under surface of the work-stone and the brick or stone bed is generally fitted up with fire-clay, or with a mixture of slime-ore and bone ashes tempered with water.

2 is the bearer, a square block 6 in. on the side and 26 in. long. There is one on each side, overhanging somewhat the sides of the hearth bottom, and thus tending to keep it firm in its place.

1, back stone, 28 in. long, 6½ in. high, and 5 in. broad. The bellows nozzle rests upon this stone.

6, pipe-stone, 10 in. square and 28 in. long, with an opening on the under side to receive the nozzle or tuyere.

5, under back-stone, 28 in. long, 4 in. high, and 5 in. wide. This completes the back of the hearth.

4, fore stone, 26 in. long, 6½ in. high, and 5 in. broad.

3 and adjacent stone, key-stones 10 in. square, two on each side. The two nearest the back are placed upon the bearers, so as to be level with them on the inside. They are 22 in. apart, but the two in front are made to lie against the ends of the fore stone 4, and are 26 in. apart.

8, cast-iron pot to receive the lead as it strikes down the channel in the work-stone.

The fore stone is movable to a certain extent, and can be placed 10 in. from the back stone by being put in contact with the two key-stones nearest the back. If necessary it can be raised by the insertion of a fire-brick at each end between it and the bearer. Its usual position is 12 in. above the upper edge of the work-stone. The various parts of the hearth are secured in their places by brickwork, and at the top it is finished level with masonry to receive any particles of ore, called hearth ends, which may be expelled by the blast or projected by decrepitation. Each hearth is placed under a chimney.

The blast is always directed downwards to the upper edge of the work-stone, as indicated by the lower dotted line, Fig. 4916.

The duration of the smelting shift is from twelve to fifteen hours. The ore having been previously calcined, is put upon the surface of the fire between the fore stone and pipe-stone by 10 or 12 lbs. at a time. The fire being made up into shape represented by the dotted line, with the flame and blast principally issuing between the fore stone, which is kept at the proper height by a fire-brick, and work-stone, a stratum of ore is spread upon the horizontal surface of the brouse or semi-reduced agglomerated ore, and the whole suffered to remain exposed to the blast for about five minutes. At the end of that time one man plunges a poker into the fluid lead in the hearth bottom below the brouse, and raises the whole up at different places, so as to loosen and open the brouse, and in doing so to pull a part of it forward upon the work-stone, allowing the recently-added ore to sink down into the body of the hearth. The poker is now exchanged for a shovel, with which the brouse is examined upon the work-stone, and any lumps that may have been too much fused are broken to pieces; those which are so far agglutinated by the heat as to be quite hard, and are further known by their brightness, the grey slags, being picked out and thrown aside to be afterwards smelted in the slag hearth. A little slaked lime in powder is then spread upon the brouse, which has been drawn forward upon the work-stone, if it exhibit a pasty appearance; and a portion of coal is added to the hearth, if necessary, which the workman knows by experience. In the meantime the opening through which the blast passes into the hearth is cleared with a shovel and a peat placed immediately above it, which is held in its proper situation until it is fixed by the return of all the brouse from the work-stone into the hearth. The fire is made up again into the shape before described, and the same manipulations are repeated. At every stirring a fresh peat is put above the nozzle of the bellows, which divides the blast, and causes it to be distributed all over the hearth; and as it burns away into light ashes an opening is left for the blast to issue freely into the body of the brouse. The soft and porous nature of dried peat moss renders it very suitable for this purpose, but in some instances, where a deficiency of peats has occurred, blocks of wood of the same size have been used with little disadvantage.

In using the ore hearth the following precautions should be observed;—The blast should be carefully regulated; if too weak the ore is not reduced, and if too strong the contents of the hearth are melted. Both these evils should be avoided, but no special rules can be given, as the same blast is not equally suitable for every kind of ore. In no case should the blast be more than sufficient to reduce the ore; the blast should be as much divided as possible, and made to pass through every part of the brouse; the hearth should be vigorously stirred at intervals, and a portion of its contents exposed upon the work-stone, when the partially-melted lumps should be well broken to pieces, and the grey slag picked out. This breaking to pieces, and exposure of the hotter part of the brouse upon the work-stone to the oxidizing action of the atmosphere, has a beneficial effect in promoting the reduction of lead, and lead always flows most abundantly out of the hearth, immediately on the brouse, after that treatment. The quantity of lime used should not exceed what is needed to thicken the brouse to the proper degree, as it does not in the least contribute to reduce the ore by any chemical effect; it is used to render the brouse less pasty, if from the heat being too great, or from the nature of the ore.

Theory of Smelting Lead Ore.—The reduction of lead ores is extremely simple. In all instances of smelting, a considerable loss of metal is experienced, which has been the cause of a close examination of the process, and we may assert that no metallurgical operation is more thoroughly and scientifically known than the reviving of lead. This metal is in most instances the bearer of silver, the bulk of which is obtained from lead ores. In order to investigate the cause of the loss in lead metal, and also a suspected loss in precious metal, much labour and ingenuity have been bestowed on this subject.

In the smelting of crude galena in a reverberatory furnace the sulphuret is at the commencement of the operation deprived of a part of its sulphur by heat; metal is formed, and as oxygen finds access to the ore, oxide of lead, and consequently sulphate of lead, is also formed. The proportion of these substances depends of course on the degree of care bestowed upon the process. When after two hours the roasting of the ore is so far completed as to admit of its reduction, the

heat is raised so high as to form a pasty mass. Oxide of lead and sulphuret of lead now mix completely and form metal, sulphuret, and sulphate, from which mixture the metal parts by force of gravitation. In mixing carbon with the slag the sulphate is reduced to sulphuret, which is again deprived of its sulphur by heat. Thus, by alternate oxidation and reduction of the ore, a certain amount of metal is abstracted. The revival of lead from the slag, causes it to be more refractory at the end to the operation than it was at first, because the sulphuret, or the oxide of lead, which was the cause of its fusibility, is chiefly removed. When the slags are so pasty as to enclose grains of metal which have not the power of separating by gravity or cohesion, they cannot yield any metal, although the whole of it may be revived. In order to obtain all the metal from the slag, it ought to be at least as fluid as the metal itself at the same degree of heat. Such a slag is not easily obtained without oxide of lead, or sulphurets of other metals. Salts of any kind, such as fluorides, chlorides, and sulphates, form the best auxiliaries in this operation; and if present only in a small quantity they are of service. Lead, bismuth, antimony, and in fact all the fusible metals, will readily separate from other matter than metals, in virtue of their gravity and cohesion, but it is a necessary condition of their separation that the matter with which these metals are combined should be fluid. The metal cannot separate from a dry slag, an agglutination of its particles is necessary before it can subside.

A fluid cinder is necessary not only for the agglutination of the metallic particles, but also for their production. When a dry or pulverulent mixture is mixed with carbon, oxygen may be abstracted from it by the carbon; but as the newly-formed particle of metal is exposed to the influence of oxygen—which it will absorb from the products of combustion if it cannot obtain it in another form—it will oxidize as quickly as it is reduced. If metallic oxides, or sulphurets and slags, are fluid, the addition of carbon to the mixture will deprive the oxidized metal of oxygen; and if the metal as well as the slags continue to be fluid, the latter will protect the first against oxygen. The fluidity of the slags will also admit of the subsidence and gathering of the metallic particles.

In smelting galena in a reverberatory, we deprive the slags gradually of the means of fluidity by abstracting that metal from them which has been the cause of their fusibility. This abstraction can be carried only to a certain point. When the slags cease to be fusible at the heat by which the metal melts, they must cease to furnish metal any further, however much may be contained in them. We perceive therefore very readily that the quantity of metal retained by the slag depends entirely on its fusibility, and not on its composition. Lead, like the precious metals, separates easily from all other matter, and thus far the composition of the slags has little effect on its quality. If in operating on galena, fluxes can be introduced which continue the fluidity of the slags at a moderate heat, all the lead, even the last particle of it, may be obtained.

The fluidity of slags depends as well on heat as on their composition; we may continue the fluidity of a slag by increasing the heat; this, however applicable with some metals, is not the fact with lead. When the heat on metals is raised beyond a certain degree, they evaporate. In any smelting operation, therefore, it should not exceed that degree. Metallic lead, and especially oxide of lead, sulphuret and salts of lead, are very volatile, and a strong heat on them must be avoided. It must be therefore the practice to smelt lead by as low a heat as possible; and in order to accomplish this, a mixture of ore must be prepared which affords a fusible slag without lead.

Lead combines very readily with other substances under certain conditions, and in most instances in definite proportions. Iron will combine with sulphur in all proportions, but not so lead. There are various combinations of lead and sulphur, which, when exposed to heat, form the combination which we recognize in galena. If less sulphur is present, metal and sulphuret are formed. This accounts for the revival of pure lead from galena that is partially roasted. In the composition of reverberatory and blast-furnace slags, we find the means of detecting the true conditions under which lead is smelted most profitably.

A slag which had been deprived of its metal by a long-continued operation in the reverberatory —sixteen hours' work—contained still 13 per cent. of oxide of lead, 53·5 oxide of iron, 11·5 barytas, and 5 sulphuret of lead; also 17 silex. This shows that the last particles of sulphur will adhere to lead, when all other substances are oxidized. A reverberatory slag, entirely free from sulphur, contained sulphate of barytas, 51; sulphate of lime, 10·5; fluoric acid, 1·5; protoxide of iron, 3; and oxide of lead, 34. A slag obtained from impure galena, that is, an ore from which heavy spar could not be separated, was composed of 30 sulphate of lead, 24 sulphate of barytas, 5·6 gypsum, 8·5 fluoric acid, 14·7 carbonate of lime, 2 sulphuret of lead, 5·6 protoxide of iron, 8 oxide of zinc. A very fluid slag which flowed off with the metal, contained sulphate of lead, 9; sulphate of barytas, 30; sulphate of lime, 33; fluoric acid, 13·6; lime, 8·8; oxide of iron, 2; oxide of zinc, 2. This contains the least lead, and large quantities of alkaline salts; all the alkaline earths are combined with some acid, which renders the compound fluid.

The last-mentioned slag is produced from crude galena which has been merely freed by hand from impurities, and for these reasons we invite attention to it. It shows a very rational operation, and one most suitable for a rough country. The ore is charged in the furnace in the common manner, and reduced so far as it will furnish metal. When the slag becomes too stiff for yielding metal, some finely-pulverized fluate of lime is thrown in and mixed with the mass. This renders the barytas and gypsum fusible, and the reduction of galena may take place. So long as the fluidity of the slag is continued, lead is formed. To render this operation profitable, fluate of lime should be used in a considerable quantity; but as this cannot be obtained always, we propose the substitution of chlorine for fluorine, which possesses in as high a degree as the latter the quality of fluxing sulphates. In this instance, gypsum and common salt may be pulverized together when damp. These form a very fluid slag with barytas, lime, iron, and other metals.

The following reverberatory slag shows that lead can be removed almost entirely from the ore, in oxidizing the mixture completely. A slag from zinc ore contained 64·5 protoxide of iron, 2·5 oxide of lead, 1 oxide of zinc, 2·5 alumina, and 29·5 silex. The iron and silex here form the

slag. It must be observed that in precipitating all the lead from a slag by means of iron, the metal will contain much iron, and be otherwise impure. When an ore contains much zinc, there is hardly any other profitable way of smelting it than to flux by means of iron, either with iron ore or pyrites; all or most of the zinc remains then in the slag.

The slags of blast furnaces differ somewhat from those of the reverberatory, in containing more silex, and in most cases less lead. A slag which was formed at a moderate heat, and considered as exhausted of lead, contained 34·4 oxide of iron, 6·6 oxide of lead, 7 lime, 9 sulphuret of iron, a little manganese and oxide of zinc, and 34·8 silex. A slag from an argentiferous galena contained protoxide of iron, 45·4; magnesia, 11·2; sulphuret of iron, 2; alumina, 3·9; and silex, 36·3. The following proportions show that a large quantity of lime is of no advantage;—protoxide of iron, 25; lime, 24; zinc, 10·6; oxide of lead, 3; alumina, 7; silex, 28·5. The following is a profitable slag;—protoxide of iron, 34·8; oxide of zinc, 6·8; oxide of copper, 2·4; manganese, 7; lime, 6·6; magnesia, 6; oxide of lead, 2; sulphuret of iron, 12; alumina, 3·4.

When ores are exposed to a low heat they hardly enter into any combination with silex, and of these the oxides only. Sulphurets, sulphates, chlorides, fluorides, and in fact all other metallic compounds, do not combine with silex; it is only after all other matter is evaporated that the oxides unite with that acid. We may smelt lead to perfection without forming any silicate, but this requires the presence of a large quantity of chlorine, fluorine, or some other permanent acid. In roasting the ores before smelting we are deprived of the advantages resulting from the fusibility of the sulphurets and acids, and are compelled to form silicates, because those substances which form a fluid slag in the low heat of a reverberatory, evaporate in the heat of a blast furnace, and are lost. When it is in our power to form a fusible slag, either by means of fluates or chlorides and sulphates, it is more profitable to smelt in a reverberatory than in a blast furnace, and precipitate the lead to within a few per cent. in the first and only operation. In this instance the ore needs no crushing and expensive washing, a removal of the coarsest pieces of quartz and of the loam is the only labour necessary to be performed on it. The presence of quartz will not influence the result, because when other acids are present it does not enter into combination. If no materials are at hand to form a fusible slag, either by natural or artificial means, then it is necessary to roast the ore and smelt in the blast furnace. In this instance the ores must be roasted, because the sulphurets are very volatile, and will not resist the heat of that furnace. The most profitable flux is the protoxide of iron. Lime or magnesia, and other alkaline earths, do not form sufficiently fluid slags to be used profitably.

When circumstances render it necessary to smelt in blast furnaces, the operation ought to be conducted in such a manner as to obtain all the lead at one smelting. This appears sometimes to be difficult, but it is not so where cheap iron ore can be obtained in sufficient quantity. When a slag or ore is to be exposed to smelting in a blast furnace, it ought to be thoroughly oxidized; because if any sulphur is left in it, even in the form of sulphate, lead and zinc are the first to evaporate. Lime does not remove sulphur, but combines with it, like all other alkalies. Iron, because it absorbs sulphur, and as easily parts with it, is the most suitable substance to mix with the sulphureous ore for the purpose of oxidation; it forms a fluid slag at quite a low heat with silex, and is thus far the best flux in the blast furnace. Manganese serves equally as well as iron, and may be substituted for it, but no other metallic oxide can be substituted for these two.

When sulphurets of lead are roasted in the air, they are never entirely liberated from sulphur; the most carefully roasted lead ore contains sulphur. Galena roasted with extreme care, in a heap, contained oxide of lead, 18; sulphate of lead, 86; sulphuret of lead, 10. The same galena, roasted during seven hours in a reverberatory, formed metallic lead, and the roasted ore powder consisted of oxide of lead, 30; sulphuret of lead, 46; metallic lead, 17; iron oxide and silex, 7. When other metals are present besides lead, such as iron, zinc, and others, they are oxidized before all the sulphur is removed. A persevering roasting of ten or twelve hours in a reverberatory furnace will remove much of the sulphur, but from 8 to 10 per cent. of sulphate of lead remains in all instances. The presence of a large quantity of silex, say 25 per cent. of the ore, is the best means for the removal of sulphur. From such ore the last trace of sulphur may be removed in the reverberatory, or in roasting it in the open air. It would not make any difference by what means sulphur is removed in roasting, and silex might serve quite as well as iron, if it could be removed advantageously before bringing the ore or slag into the blast furnace.

In practice at the furnaces, we find the above principles operate under forms modified by local circumstances. The smelters at a reverberatory furnace alternately cool and heat the furnace, in order to oxidize and reduce, by means of granulated coal. A fluid slag cannot quickly oxidize; it is like melted metal in this respect; there are no points of contact for the oxygen. The drying up of the slags, by cold or drying flux, such as lime, facilitates the oxidation of the sulphuret. The best plan is to run the metal and slags out continually, the first into a heated iron pan, the latter over damp charcoal-dust. This mode of operation causes oxidation quicker than any other. When the slag is cooled, it may be recharged or reserved for the slag furnace. Slack coal should never be mixed with the slag for reduction; a granulated coal assists in forming large globules of metal; it affords points of oxidation for the slag, and does not stiffen it so much as fine coal. When litharge is reduced in a reverberatory, it does not work well if both coal and litharge are fine; this is not from want of affinity or other secret causes. The powdered mass does not admit of the formation of a large globule of metal, or of motion in the fluid metal, which is necessary for agglutination. And as oxide of lead, particularly when mixed with a refractory substance, does not melt at so low a heat as metallic lead, the whole mass must be heated until the mixture of oxide and coal begins to become fluid, and admits of the subsidence of the metal. Litharge is easily reduced in the reverberatory. A charge, consisting of 1 ton of litharge, may be smelted in 1½ or 2 hours, when in a granulated form, but when finely-ground litharge or fine coal is used, twice as much time is required. When the heat must be urged so high as to melt the litharge, the process is slow. We find the principle of the operation here to be different from that of smelting

ore; if, in the latter case, we work the ore dry, as litharge, we produce but little metal. The cause of this is, there are impurities and metal in close contact in the ore, and no large globule of metal can be formed, because the foreign matter interposes between the particles of metal.

The conditions under which successful smelting may be performed are therefore very plain. A fluid slag is in all cases required where impure ore is to be smelted; pure ore, or litharge, may be worked more dry than impure ore. Fusible slag may be produced by a variety of means, of which heat is the most available, but not the most profitable. High heat causes a loss of metal by evaporation; it brings foreign metals into the lead, which are injurious to its quality. Lead ought to be smelted at the lowest heat by which it can be melted. A low heat, or quick work, will produce the best metal in all instances, and as that kind of work demands less fuel and labour, too much attention cannot be bestowed on this subject. Fusible slag should be formed by means of fluxes, not by heat, which will, in most instances, remove those ingredients which cause fluidity. Protoxide of iron, which is most successfully formed of powdered hematite ore and carbon, forms readily a fusible slag, in the presence of chlorine, fluorine, sulphuric, phosphoric, or any other acid; but these acids are soon evaporated by a strong heat.

Smelters dislike the use of much iron in a reverberatory as well as in the blast furnace, because in its most fluid condition it acts upon the stones, bricks, and slags of which the hearth is formed, and causes their premature destruction. When the work is done on a fine charcoal or coke hearth, in the presence of much iron, it is reduced with the lead, and impairs its quality. We recommend for these reasons, for smelting lead, the application of cooled boshes, and cold cast-iron bottoms, such as are used in puddling furnaces. In the slag hearth and blast furnace, iron plates are generally used below the tuyere, and are lined with clay or coal-dust, but both these materials for linings are injurious as well to the quality of the metal as to the yield. There cannot be any disadvantage in surrounding a slag hearth with cooled iron plates, similar to a run-out fire for refining iron. A little more fuel may be used in smelting, but a more fluid cinder can then be employed than in any furnace, which of course tends to economize fuel, and causes a purer article of metal.

Lead Smoke.—At the smelting furnaces, particularly at those where the operation is performed at a high heat, a white smoke is thrown out at the tymp, or at the top of the furnace. This may be gathered in condensing chambers, as in Fig. 3089. Similar chambers may be annexed to reverberatories. This white smoke contains those metals which are in the ore. A reddish dust from a reverberatory contained 11 oxide of lead, 60 sulphate of lead, 2 arsenious acid, 15 oxide of zinc, 12 oxide of iron. When there is much zinc in the ore, and it of course evaporates, a large quantity of silver is carried away by it. Iron and coal are generally the colouring matters in the body of these deposits. It is always found to be chiefly oxide and sulphate of lead.

Action of Lead upon the Animal System.—The compounds of lead exert a deleterious action upon the animal system. Persons suffering from this action experience morbid phenomena, the intensity of which is variable. The first degree of saturnine poisoning is characterized by a violent and general disturbance of the system, and is known as lead or painters' colic. The second degree consists in the extension of the preceding pains, which are confined chiefly to the stomach, to the limbs, and especially to the joints; this is known as lead rheumatism. The third degree causes a paralysis of the limbs, which usually shows itself first in the extensor muscles of the wrist, and is termed lead palsy; and, lastly, in certain cases, disease of the brain may be induced, which generally terminates in delirium and death.

In the first stages the poison may be combated by means of powerful purgatives, which facilitate its elimination from the system. It has been proposed that men who work on lead should drink sulphuric lemonade, and often take sulphurous baths, followed by a copious use of soap. This preventive treatment is intended to hinder the absorption of the lead taken into the stomach as well as that deposited upon the skin. It appears, however, that the lemonade produces very bad effects, for, by rendering the lead insoluble, it fixes it in the intestines, where it finally gets absorbed. The best treatment in the case of lead colic consists in the use of purgatives and nitric lemonade.

See Bullet Machine. Founding. Furnaces. Ores, *Machinery and Processes employed to dress.* Silver.

Works on Lead:—Foster (W.), 'Treatise on a Section of the Strata from Newcastle-on-Tyne to Cross Fell in Cumberland,' 8vo, 1821. 'Records of Mining and Metallurgy,' by Phillips and Darlington, 12mo, 1857. Lamborn (J.), 'Metallurgy of Silver and Lead,' 12mo, 1861. Wallace (W.), 'On the Laws which Regulate the Deposition of Lead Ore,' 8vo, 1861. Percy (Dr.), 'Metallurgy of Lead,' 8vo, 1870.

LEVELLING. Fr., *Nivellement;* Ger., *Nivellirung;* Ital., *Livellazione;* Span., *Nivelacion, Agrimensura.*

See Surveying and Levelling.

LEVER. Fr., *Levier;* Ger., *Hebel;* Ital., *Lieva;* Span., *Palanca.*

See Mechanical Powers.

LIFTS, HOISTS, AND ELEVATORS. Fr., *Monte, Charge;* Ger., *Gichtanfzug.*

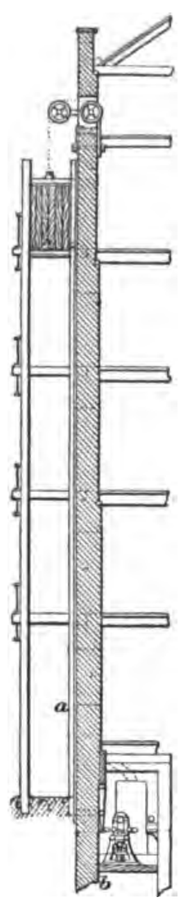
Lifts, hoists, and elevators, are a class of apparatus used for concentrating power at a particular point, and utilizing it to effect the raising or lowering of bodies. A lift is only properly so called when the raising medium is applied above, and should be called a hoist when it is applied below, or an elevator when it is continuous.

In many London warehouses an effective lift is used, arranged with four iron standards, which extend the extreme height of the lift, rest upon an iron bed-plate, and support the top frame. Upon the sides of the top frame are fixed two brackets. A sheave is attached to the outside of an axle working in bearings on the brackets, this axle carrying the lift pulley, and a toothed wheel gearing into a pinion which is fixed on another axle turning upon its outer end the friction-wheel of an Appold's brake, similar to that in Figs. 1268 and 4495. The cage is furnished at each corner with guide-wheels, which run upon the standards; it is attached by means of a rope with a counterweight

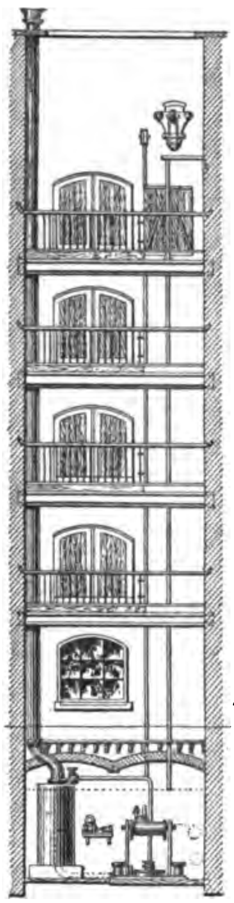
working in grooves at the side of the apparatus. The hauling rope passes over the sheave on the head-frame, and under another sheave mounted in a slot at the side of the bed-plate, and adjustable vertically. Both the hauling rope and the rope working the friction-strap are accessible from every floor the lift passes through.

An ordinary form of steam-lift used in the large London warehouses is shown in Figs. 4917, 4918. It consists of a cage suspended from a single chain, and running between light angle-iron guides outside the wall of the warehouse. At each floor is an external landing, supported by a girder, Figs. 4917, 4918, the goods from the cage of the hoist being delivered on to these landings. The total height of the particular lift, Figs. 4917, 4918, is 42 ft. 6 in., and the load taken up is

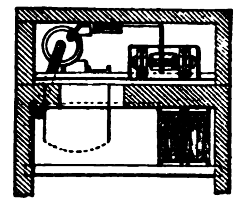
4917.



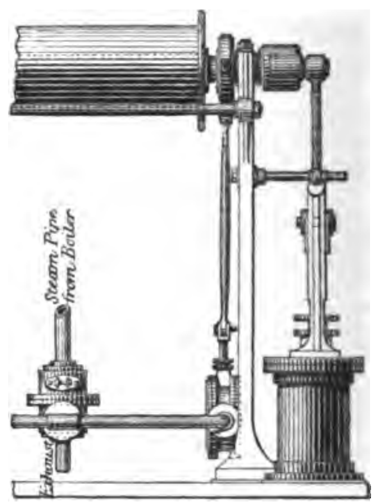
4918.



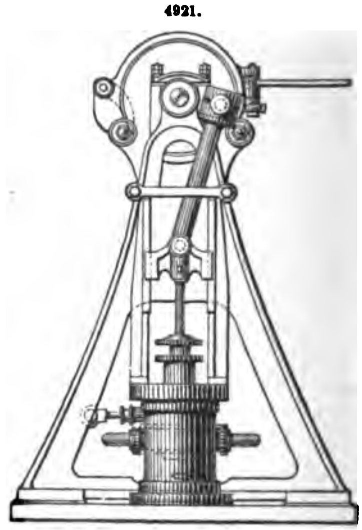
4919.



4920.



4921.



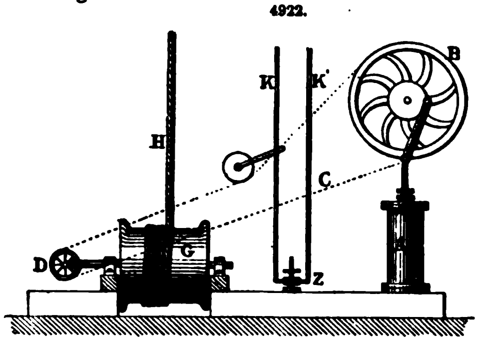
10 cwt., besides the weight of the cage, which is 4 cwt. The lifting is performed at the rate of 150 ft. a minute.

The chain from which the cage is suspended passes over two pulleys, and then down to the hoisting engine, which, together with its boiler, is situated in a cellar, Figs. 4917 to 4919. The hoisting engine, partly shown, enlarged, by Figs. 4920, 4921, has a pair of cylinders 7 in. in diameter, by 10 in. stroke, the connecting rods being coupled to cranks fixed at the ends of the shaft carrying the chain-barrel. This barrel is 9 in. in diameter, and is provided with a powerful brake, consisting of a strap which encircles an enlarged part of the drum, and which can be tightened by a screw, Fig. 4921. The lever by which this screw is turned can by means of a rod be moved from any one of the floors. The engine is fitted with a simple reversing arrangement, consisting of a valve by which the steam-exhaust passages can be interchanged; and provision is made for stopping or starting the engine from either floor. In practice the lowering is almost always performed by steam, the brake being but seldom used.

All American houses of business are provided with lifts for the purpose of raising goods from the street to the first story. So general is the custom of employing this means of receiving and dispatching merchandise, that the single-story house of the meanest tradesman of New York has at least a rope and pulley for lifting packages. The lift, which is fixed to the street wall of buildings, consists essentially of a platform about 5 ft. by 3 ft. 6 in., suspended by four chains, which, after passing over six pulleys above, are reduced to two as they descend, and are fixed to two windlasses having a common axis, and capable of being turned by four levers at once.

Fig. 4922 is an elevation, Fig. 4923 a plan, and Fig. 4924 a top view of portions of a New York steam-lift. Fig. 4925 is a section through *m n*; and Fig. 4926 a section at *o p*, Fig. 4924. A A are small steam-cylinders; B, C, D, belting transmitting motion from the pulley B to D, and thence by means of a screw and tangent-wheel to the drum G; H H, hauling rope running over the pulley N and lifting the cage; K K', regulating rope running under the pulleys J J and over the pulley R to the horizontal pulley Z which regulates the introduction of the steam; Q, movable counterweight.

4922.



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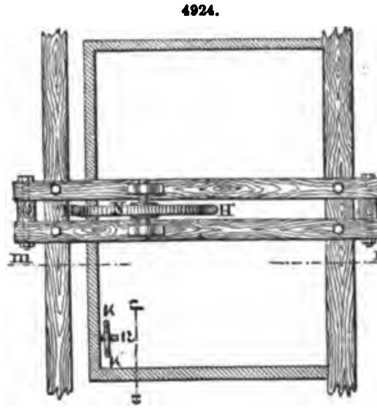
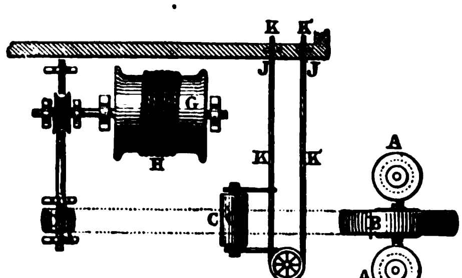
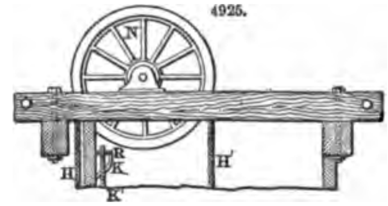


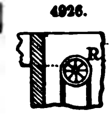


4923.

4925.



4926.



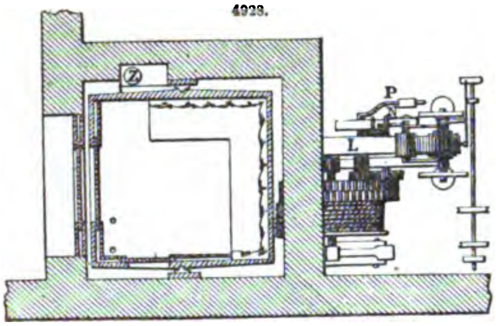
When the goods have been taken in and verified, they have to be taken up into the upper stories of the house; and for this purpose all the floors are pierced with a rectangular opening to allow the passage of a lift. The primitive system of the single pulley has been improved upon; on the one hand, by substituting a windlass at the top of the house for the pulley, worked by a man who is directed in his movements by a signal bell, and on the other hand by substituting a platform, rigidly fixed by means of four iron rods to a frame above, for the hook at the end of the rope. The necessity of keeping a man constantly at the top of the house may be avoided by providing a roller or drum in addition to the windlass, and passing the winding rope two or three turns round it. By bringing the end of the rope down again to the platform, it will constitute an endless band, and the lift may in this way be worked from below.

In many houses the lift almost wholly takes the place of staircases, both for persons and goods, for the *personnel* of the house and for strangers. In such cases the requisite motive power is much greater, and often the employment of steam-power becomes economically necessary.

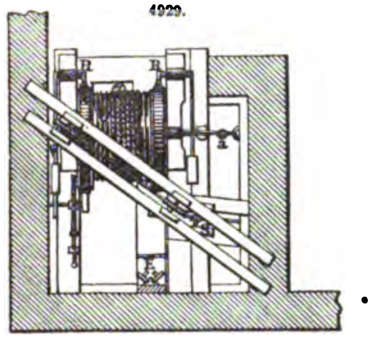
The rectangular space in which the lift moves is usually lit by a row of windows one above the other on one side, and on the other side it is open to the landing-places corresponding to the different floors. The lift itself is sometimes a simple platform, sometimes a small room furnished with couches, adorned with mirrors, and, in the evening, lit with gas. These are to be found in the large hotels. The luggage, in this case, is placed in a special compartment beneath the floor of the saloon. The lift is suspended by iron or steel wire rope, passing over a pulley at the top and down, outside the left case, to the lower story, where the engine is erected. Two men only are required to work the lift; one to attend to the engine, the other to control the lift. Various appliances have been introduced to prevent accidents from over-winding, or from a breakage of the winding tackle, and the success which has attended their use seems to have averted all danger from this source.

When the platform of the lift is very heavy, a counterpoise is used. In Atwood's system the counterpoise weighs as much as the platform; they are connected by a rope which passes over a pulley above, and the space passed through is equal for both. In Otis's system, a counterpoise of twice the weight acts upon a drum keyed upon the same axis as another drum of twice the radius, around which the lift-rope is wound. The space passed through by the counterpoise is therefore half that passed through by the lift.

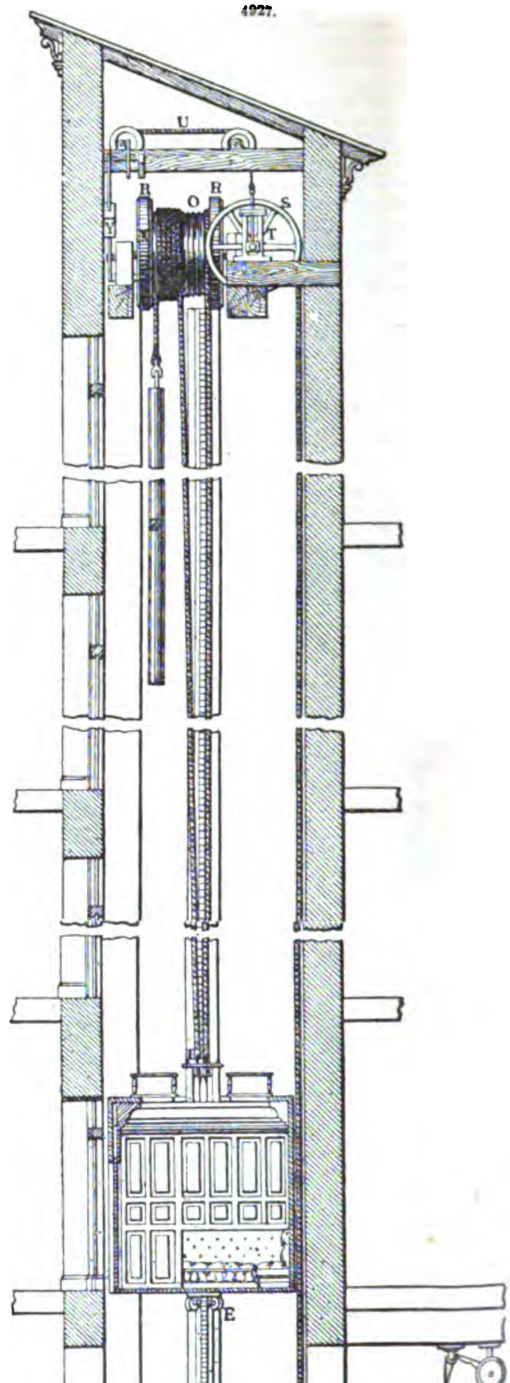
4928.



4929.



4927.



Figs. 4927 to 4929 are an elevation, plan, and top view of a safety passenger lift, by Otis Brothers, of New York.

The engine is double cylinder and reversible: both cylinders being connected to a single shaft, with cranks set at right angles, to avoid stopping on centres. Steam is permitted to pass to, and the exhaust to pass from the cylinders through a single valve, which is arranged to reverse the current or check the flow of steam by a simple movement or change in the position of same. The same movement which shuts off the steam from the cylinders, also closes the exhaust orifice, and renders further motion in the engine impossible. By this means the car is always under control, both in the upward and downward movement, so long as the gearing and connections remain intact The orifices in reversing valve communicating to and from cylinders, when the car is making the downward trip, are graduated to suit the changed relation and action of the loading, and any excessively rapid motion is thus prevented.

Combined with the engine and hoisting gear is a brake P, which is arranged to be brought into or released from action simultaneously with the stopping or starting of the engine, causing no unnecessary friction while the machine is running, but holding the entire apparatus immovably when it is required to stand at any point to receive or discharge loading or passengers.

The engines are designed to run from one hundred to three hundred revolutions a minute, giving the car a motion varying from 50 to 150 ft. a minute; the rate of speed being always under the immediate control of the operator in the car.

To prevent the noise as well as to avoid the jar necessarily attending the use of gearing at a rapid rate of speed, motion is communicated from the engines to hoisting gear, at the first remove, by means of a powerful belt L. The second and third combinations required in extending the connection to the large winding drum M, are made

by means of accurate machine-cut gearing, each change in train of gear being effected in duplicate, the teeth in the one being placed opposite the spaces in its counterpart.

The winding drum is of a large diameter, grooved spirally to receive the wire rope and prevent the successive coils from coming in contact.

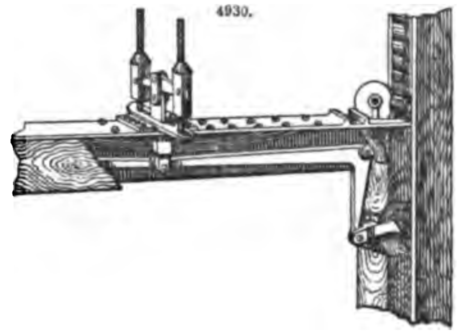
The peculiar character of the duty required to be performed by the hoisting engine in connection with this system of machinery, renders necessary a given number of revolutions alternately in either direction, and the impossibility of a greater number of revolutions of the winding drum than are required to allow the car to reach the extremes of its run. To provide for this, a simple mechanical device called the stop-motion is placed at N; by its means the engine is readily limited to the required number of revolutions in either direction; having accomplished which, steam is shut off, the brake applied automatically, and the engine cannot be again started except in the opposite direction.

The car is substantially built of hard wood and wrought iron—designed to combine the greatest possible strength with the least weight of material. The running gear, by which the car is securely kept in place, and guided in passing through the hatchways, consists of a system of rubber-faced wheels E, acting upon planed iron guides D, which extend from the lowest to the highest points of the hatchway on its two opposite sides or corners.

By the employment for this purpose of wheels having peripheries of hard rubber, properly supported by iron flanges, security against displacement is obtained, while there is sufficient elasticity to compensate for any slight variation in the relative positions of the guides, and ensure a bearing at all points, and freedom from any rattle or irregularity of motion.

The safety appliances in connection with the car consist of heavy iron pawls, Fig. 4930, combined with powerful steel springs, and suitable mechanism for forcing the pawls into contact with the safety ratchets, in case of parting of the lifting rope.

4930.



These safety attachments are applied in duplicate; each set being independent of the other, and capable of sustaining the entire weight of the car and loading.

The safety ratchets D, Fig. 4927, which, in connection with the safety fixtures attached to the car, form a very important dependence in case of accident or derangement to the lifting ropes or other working parts of the machine, are in effect a mechanical device for reducing to three inches the distance which it is possible for the car at any time to fall, in case of breakage of the lifting ropes, a practical following up of the ground floor three inches below the car.

These safety ratchets are of iron, very heavy, and having the strongest possible form. The lower ends have a firm bearing at the ground, and the two lines are extended perpendicularly to the highest point to which the car is to rise. The formation of the safety ratchets is such as to present a series of hook-shaped cogs to the pawls K, attached to the car. These cogs and the pawls which act upon them, have a peculiar conformation which ensures a locking together of the two immediately following the slightest contact at the points, and also renders a separation impossible except through the instrumentality of the lifting rope, when properly connected and in order for work.

The safety drum O is an auxiliary safety device, designed to guard against a class of accidents generally resulting from some derangement in the machinery, or obstruction in the hatchway, causing the ropes to be uncoiled from the main winding drum of the engine, while the car remains temporarily lodged at a greater or less distance from the bottom. It is also a safeguard against a rapid descent of the car, in case of the gradual or sudden giving way of the belt, or any part of the gearing connected with the engine; and will prevent a too rapid running of the machine.

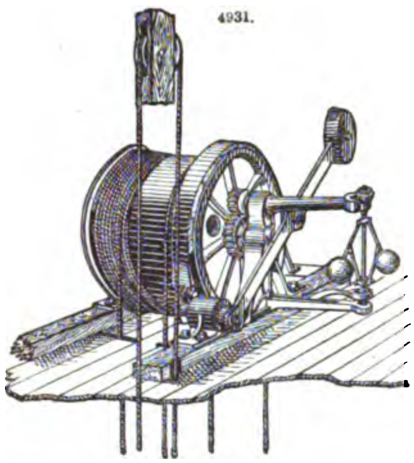
Accidents resulting from any of the above-mentioned causes cannot be guarded against or prevented by a simple multiplication of the lifting ropes, or by any of the usual appliances for preventing mishaps. The safety ratchets and pawls are perfectly reliable in case there is a sudden and perfect separation of the lifting ropes at any point in the hatchway, directly over the car, and between the car and the roof or sheave-wheels over which the ropes turn in descending to the main drum of the engine. So soon, however, as the ropes have turned these sheaves, their weight and the friction caused by them serve to retard the movements of the springs I, and counteract their effort to force the pawls into contact with the ratchets. Hence to increase the number and weight of the lifting ropes but adds to the danger, in case of accident to the ropes at any point excepting between the car and the roof. Any breakage of the gearing or other part of the hoisting engine, or of the ropes at a point near the engine, would therefore result in a letting down of the car, unless prevented by some additional safety appliances.

The safety drum takes the place of the ordinary sheave-wheels, and acts as the medium through which motion is communicated from the engine to the car. All ropes connecting from the engine to the car are arranged to act upon this drum, in such a manner that any derangement in their bearing or change in their action, or increase of their motion beyond that prescribed as the regular working rate, will immediately bring into action the two powerful brakes R R, and thus instantly stop the entire apparatus.

The sheave S, around which one of the main lifting ropes passes in leading from the engine to the car, has its bearings in the sliding frame T, which is connected by means of the chain U to the weight on the brake-lever V. So long as the weight of the car is supported by the rope W, the

sheave will be depressed, the brake-lever raised, and the brake kept free from the large friction-wheel X. But if by any means the weight of the car should be taken from this rope, the sheave would be drawn up by the gravity of the weight V, and the brake R be immediately brought into action, stopping and securely holding the drum and effectually preventing any further motion so long as the rope remains slackened. At the same time, the safety pawls in the car, with which this rope connects, would be forced into contact with the ratchets by the spring I, and the car would thus be doubly secured against falling. The rope V connects from one set of the safety fixtures in the car directly to the safety drum, and is firmly secured to it. This rope is successively coiled on to and uncoiled from the safety drum, as the car ascends and descends, by the action of the car and the weight Z; the weight also acting as a partial counterpoise to the car. The brake R on the opposite end of the drum is arranged very similarly to the one first described, but is only brought to bear upon the wheel by the action of the governor *a*. So long as the speed of the drum and car does not exceed the prescribed limit, this brake is kept free from the wheel by a simple mechanism connected with the governor; but is immediately thrown into action by the governor when the speed from any cause reaches a rate at which it is designed that the machine should not be run. The apparatus is controlled by a small endless wire rope passing through the car.

4931.



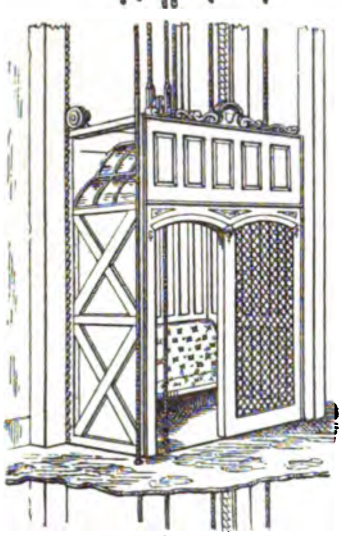
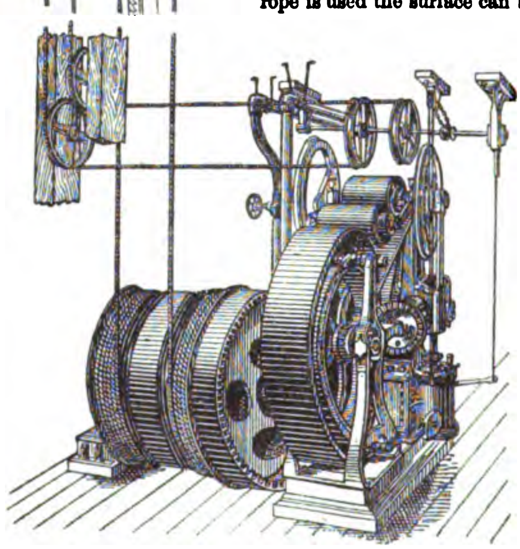


Fig. 4931 is of Otis Brothers' Metropolitan Elevator. This lift comprises a double-cylinder and reversible steam-engine. Figs. 4932, 4933, a winding drum immediately connected with the engine; a safety drum, Fig. 4934, placed over the hatchway, guide posts at each side, or two corners of the hatchway from cellar to roof, faced with the lock ratchets, between which the platform is raised and lowered by a wire lifting rope, suspending it from the safety drum, which another wire lifting rope connects with the winding drum at the engine. The platform is moved from 60 to 200 ft. a minute at will of operator, and wherever it is stopped it is immovably held by a powerful brake combined with the engine and winding drum. This brake is so arranged as to be brought into and released from action simultaneously with the stopping and starting of the engine, but causing no friction while the lift is running. This lift differs but little, except in arrangement, from the one just described.

Fig. 4934A is of a winding drum for lifting, made by William Sellers and Co., Philadelphia. The drum is arranged either for a wire rope or a chain. When a wire rope is used the surface can be covered with leather to prevent abrasion. This drum is driven by a tangent-wheel and worm enclosed in a casing, where they are submerged in oil, the oil being retained by packing glands on the worm-shaft. The whole is driven by pulleys, the motion being reversed as in a planing machine, by shifting the belts. See MACHINE TOOLS.



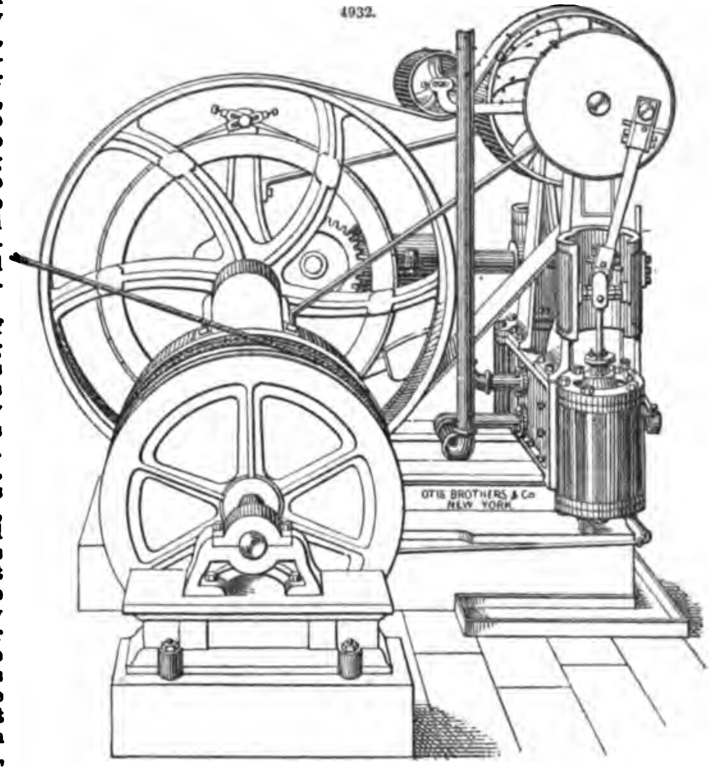
The gearing for shifting, seen on top, is the same as used on the "Sellers Planing Machine," and is so arranged that one belt is removed from the central or fast pulley before the other belt is thrown on. The shifting drums are operated by hand, either by cords or a vertical rod that is partially rotated or moved up and down as the nature of the case may render most convenient. The vertical shafts on the front

are operated by a tangent-wheel in the casing, which serves as a guard to shift the belt at the extremes of the run of the cage or platform suspended on the drum. The small quadrant seen in front is to move a cord or chain by which the hand movement of the shifting gearing is effected.

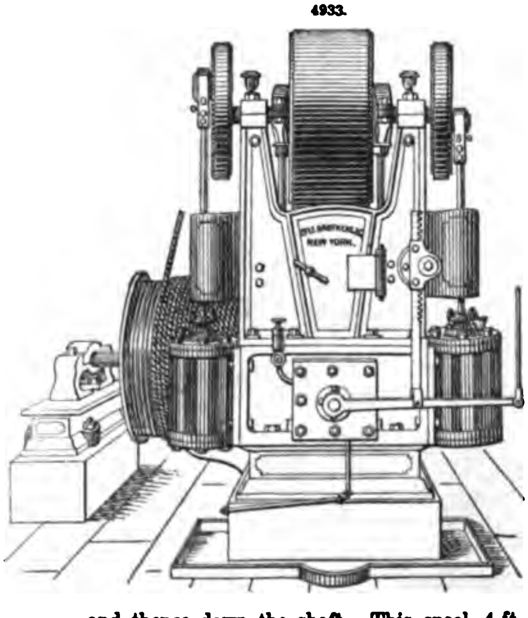
Fig. 4935 is a view of another of William Sellers and Co.'s winding drums, driven by a train of spur-gearing. The friction pad is operated by the shifting gearing, and stops the movement instantly, after the belts are shifted, by pressing on the fast pulley in the centre; the shifting devices are on the front, and show the form of the pivoted shifters that produce the differential movement before referred to.

In the mines of Colorado the lifting arrangement consists of a bucket which is raised or lowered by a winding apparatus driven by belting. This contrivance, Figs. 4936, 4937, is very simple, and, though not well adapted to deep shafts or heavy work, it answers its purpose very well in shallow mines. The drum, or spool *a*, on which the rope is wound, is placed near the mine-shaft, so that the rope passes from it over a pulley *b*, and thence down the shaft. This spool, 4 ft. in diameter, is fixed on an iron shaft *c*, having at one end a pulley *d*, of somewhat larger diameter, and at the other end a brake-rim *e*. Motion is communicated to the pulley *d* by means of a driving pulley directly beneath it, and on

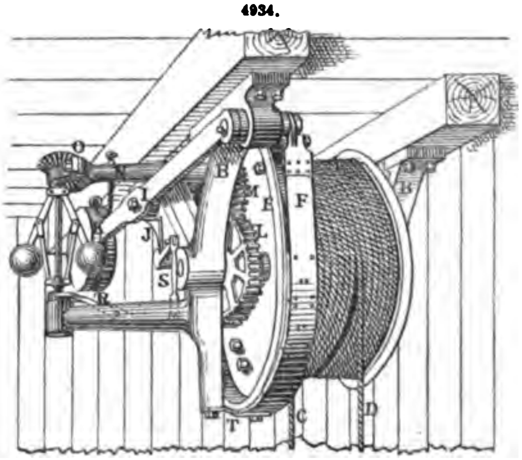
4932.



4933.

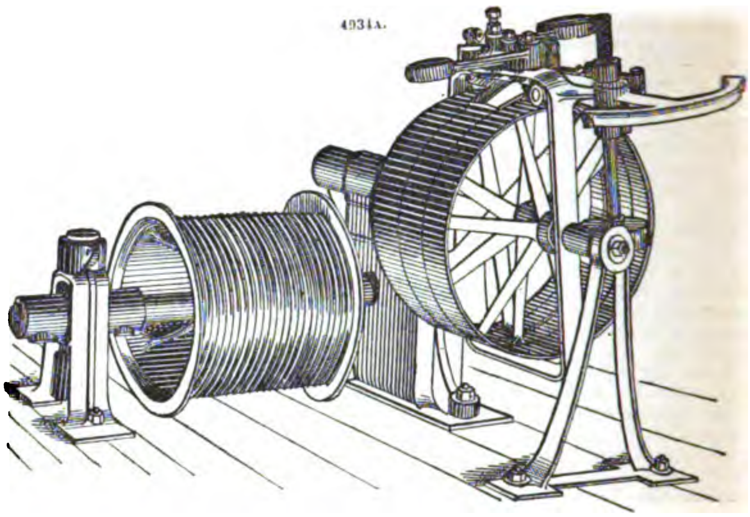


4934.

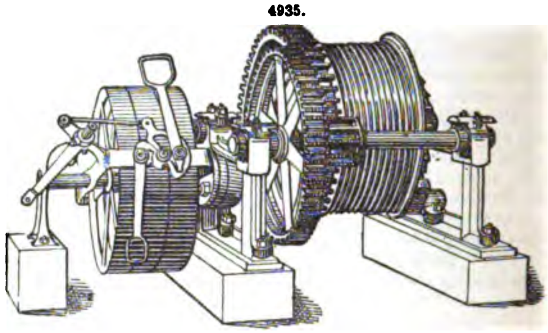


8-in. belt *g*. This belt is slack, and imparts no motion to the spool unless the tightener *h* is applied to the belt by means of the lever *j*, which is done by the attendant standing at the mouth of the shaft, whenever it is desired to lift a bucket from the mine. On withdrawing the tightener, the spool is held firmly, or its reverse motion is controlled by means of a brake, a 4½-in. iron band, encircling the spool at the rim *e*, and applied by the lever *i*. The pulley driving the belt *g* is on the same shaft with, and concealed from view by, the pulley *k*; to this motion is communicated by the belt *l*, and the pulley *m*, which receives its power directly from the engine. The pulley *m* drives a long shaft *n*, extending from the building in which the machinery is enclosed to the other shaft-houses of the mine, where winding of similar character is set in motion in the same manner. Power is sometimes transmitted in this way a distance of several hundred feet, from an engine to a remote shaft-house.

4934A.

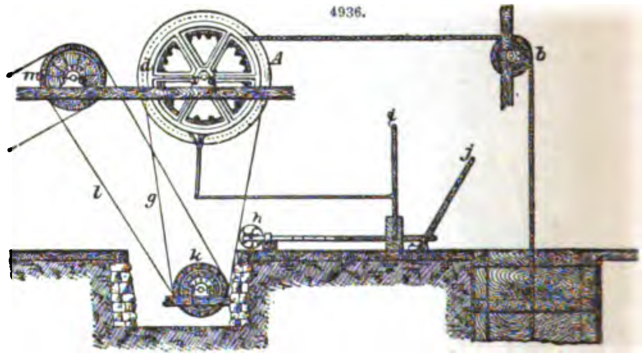


4935.



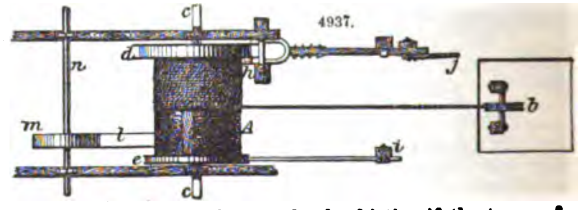
At the Comstock Mines, in Nevada, the winding reels or drums are operated either by cog or friction gearing. The latter was much used a few years ago, but as the depth of the mines has increased it has been abandoned by some, and replaced by cog-gearing, which is thought safer and more effective for deep works.

4936.



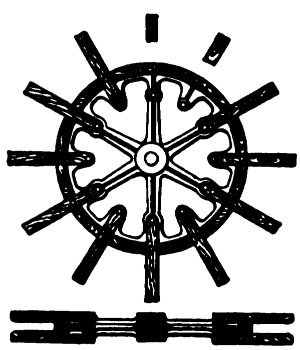
The kind of friction-gear formerly in general use is that known as the V-wheel and pinion; the construction of which is shown in detail in Fig. 4938. The face of the wheel, usually about 8 or 10 in. wide, is formed with V-shaped grooves, two or three in number, which extend, continuously, entirely around the periphery; the face of the pinion is of corresponding form, but it is so placed with regard to the wheel that the projecting ribs between the grooves fit into the recesses in the face of the wheel. The pinion is keyed to the engine-shaft, and may be set in revolution by it. The wheel, being so placed that its face may be brought into contact with the face of the pinion, is caused to revolve by friction if the two surfaces of wheel and pinion are forcibly pressed together. The friction-wheel forms one end of, or is

4937.



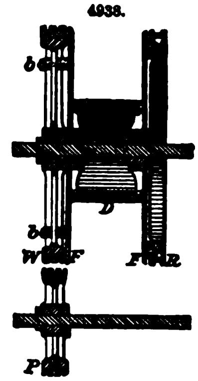
attached to the drum on which the rope or cable is bound. In Fig. 4938 the wheel W is cast in one piece, and the drum or spool consists of two flanges F F, which are connected together by plates of iron, bolted as shown in the figure. The spool is joined to the friction-wheel by bolts b b, passing through the flange F. To the opposite flange F is bolted a broad rim R, to which is applied a brake-strap. This strap is usually a band of iron, 4 or 5 in. wide, which encircles the rim R of the spool, and may be made to grasp it tightly, thus arresting the movement. There are various methods of applying the brake to the rim; one of them is shown in Fig. 4939. L is a long lever, broken off in the drawing.

4943.



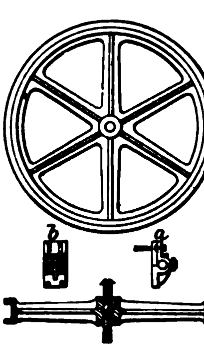
4944.

4938.

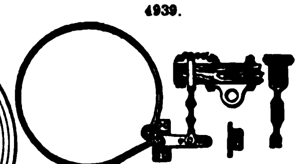


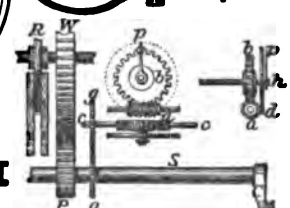
The general method of arrangement of machinery of this kind is illustrated in Figs. 4940, 4941. In this case there are two drums, each of which is independent of the other. The friction-pinions P are keyed to the engine-shaft S, and are caused to revolve by it. Each friction-wheel W forms a part of a winding drum D, which is supported by pillow-blocks B, that may slide backward and forward on the bed-plate beneath them. They move horizontally between guides and flanges, which prevent any upward motion. The sliding movement is imparted to the pillow-blocks by means of the arms a, connecting them with a short lever at b, which is keyed to a rock-shaft c. If this rock-shaft is slightly turned towards the drum, the arms are advanced, and the friction-wheel brought into contact with the pinion. If it is turned from the drum, the wheel is removed from such contact, and may be held by a brake. The desired motion is given to the rock-shaft c by the short lever l, and the long arm L, which is at the hand of the attendant. On the opposite end of each drum is a rim R for the brake-strap. The brake is controlled by the short lever f, and the arm F, which, like the arm L, is within easy reach of the operator.

4945.



4939.

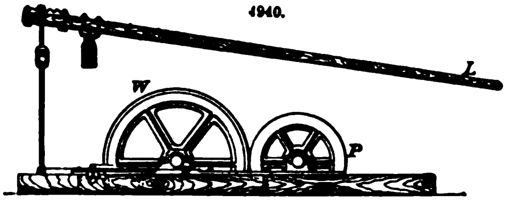




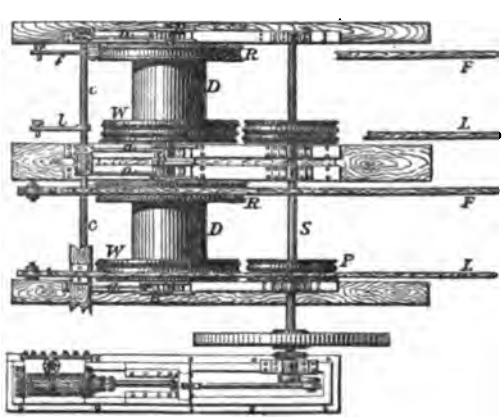
4946.

This method of operation has some advantages in the simplicity with which the machinery is controlled, and economy in the labour employed. The engine runs steadily in one direction, and, not having to be reversed, requires but little attention. It may also be applied to other continuous work, such as pumping, the driving of air-blowers or other machinery which cannot be done when the engine is stopped and reversed at short intervals.

4940.



A disadvantage of this method is, that with very heavy loads the wheels are liable to slip against each other; and another, that it is not readily practicable to lower a loaded cage into the mine under control of steam, making it therefore necessary to depend entirely on the brake for that purpose. This is particularly objectionable in deep mines, where the weight of the long cable is itself very considerable.

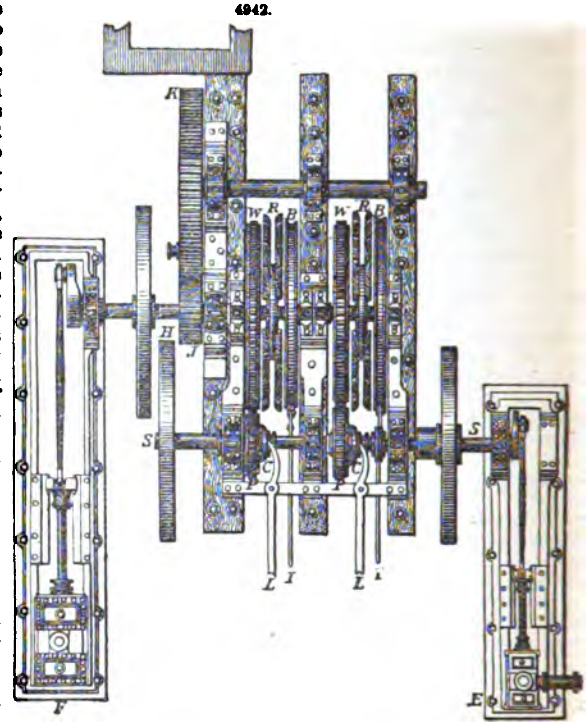


4941.

Fig. 4942 is a plan of another arrangement of lifting apparatus, used in Nevada. In this case two reels R R are each keyed to a separate reel-shaft with a spur-wheel W and brake-rim B. The reels are entirely independent of

each other. There are two pinions P P, one for each reel on the engine-shaft S. These pinions are not keyed to the engine-shaft, but turn freely in either direction, independently of the motion of the shaft. They may be made to revolve with the shaft by the clutches C, which being fixed to the shaft by a feather may slide toward or from the pinions. If the clutch C is moved into gear with the pinion P, the latter receives the motion of the engine-shaft, and transmits it to the reel. If the clutch be withdrawn from its contact with the pinion, the reel may turn in the opposite direction, while the motion of the engine remains uninterrupted. The reel may therefore be moved by the engine for lifting, and when reversed for lowering may be controlled by the brake. The clutches are moved in and out of gear by the levers L L, and the brakes applied by similar levers I I. If it is desired to lower a cage under control of steam, as is usually the case when men are descending, it is only necessary to leave the clutch in gear, and reverse the engine. It will be seen that both reels may lift at the same time; or, by fixing both clutches permanently in gear, and reversing the engine for each operation, one reel may lift while the other lowers, using the descending cage as a counterweight for the ascending one. By this arrangement the single engine E may not only do the lifting, but also drive the pumps. The engine-shaft extends beyond the reels, and if the wheel H is moved into gear with the pinion J of the pump-wheel, K may set that in motion. The pumping engine F is commonly used for this purpose, but in case of necessity its work may be done by the hoisting engine E. Lifting may also be performed by the pumping engine, if the wheel H is put in gear with the pinion J. Thus, if desired, either engine may serve as a substitute for the other.

4942.



The cables commonly employed in the lifting works of the Comstock Mines are either flat ropes, of steel or iron wire, or heavy round hemp ropes. Chain is used very rarely, if at all. Flat ropes are generally preferred, especially for great depths, because they possess greater strength in proportion to their size, winding themselves compactly upon a reel, and withstanding better than the hemp the wear and tear of the work. They are usually from 3½ to 5 in. wide, and vary in thickness according to the character of the material of which they are made. If of iron wire, they are from ⅜ in. to ⅝ in. thick; if of steel, they are usually ⅜ in. in thickness. The latter is preferred, on account of its lighter weight, less bulk—an important consideration when the space allowed for winding reels is limited—and greater strength. Flat ropes are wound on narrow reels, the width of which is but very little greater than that of the rope. The latter therefore winds upon itself at each revolution of the reel. Figs. 4943, 4944, are a common form of the reel used. It is a central wheel of cast iron, 6 or 8 ft. in diameter, to which are bolted a number of wooden arms, making the total diameter about 12 ft. They are sometimes cast with a rim, for the application of a brake. For hemp ropes, spools or drums are used, one form of which, combined with a friction-wheel, is shown in Fig. 4938.

The rope or cable passes from the reel or spool over a sheave, which is supported directly above the hoisting shaft, and thence downwards into the mine, its end being attached to the cage or bucket.

The sheaves are made of wood or iron, and of various dimensions. Those of large diameter, 8 or 10 ft., are preferred, as they cause less wear to the cable. A sheave of common form is shown in Fig. 4945. It is made of cast iron, and is supported upon pillow-blocks *a b*, in a gallows-frame which is built at the mouth of the shaft, and so placed with reference to it that the rope passing over the sheave may be suspended over the middle of the compartment in which it is employed.

The position of the cage in a shaft, at any part of its ascent or descent, is shown to the operator by an indicator, Fig. 4946, connected with the winding machinery. In Fig. 4946, S is the main engine-shaft, set in motion by the crank C. The pinion P drives the spur-wheel H, by means of which the winding reel R is caused to revolve. The relation of the pinion to the spur-wheel being as 1 is to 3½, the winding reel R makes 100 revolutions for 350 of the engine-shaft. On the latter, near the pinion P, is fixed a light gear-wheel g, 2 ft. in diameter, which drives, by means of a similar wheel g', the counter-shaft c. This counter-shaft has a worm, shown at a in elevation, above which is a worm-wheel b, a disc 2 ft. in diameter, the periphery being cut to correspond with the worm a, and has 350 threads. As the counter-shaft c and worm a revolve with the same peed as the engine-shaft, the disc b is caused to make one complete revolution by 350 revolutions

of the engine-shaft = 100 revolutions of the winding reel R. The journal supporting the disc projects beyond its face, and is provided at h with a pointer p revolving with the disc. Between the disc and the pointer a dial b, fixed upon an independent support, is interposed. As the disc is revolved, the pointer moves over the face of the dial. As the pointer moves with the disc, its position is always determined by the length of cable paid off from the reel; if its position is once marked on the dial at points corresponding to given depths of the mine-shaft, the engine-driver can readily ascertain the place of the cage.

Cranes.—In common *jib-cranes* the ordinary height of handle above the ground is 3 ft., and the diameter of the circle described by the handle 32 in., while the angle of the jib should be = 45°.

Each man working at the handle of a crane imparts a pressure of about 15 to 20 lbs., and taking W = weight to be raised by crane in lbs., P = power applied to the handle in lbs., D = diameter of circle described by handle in inches, n = number of revolutions of handle to one of barrel, B = diameter of barrel in inches,

$$B = \frac{D \times P \times n}{W}. \qquad n = \frac{W \times B}{D \times P}. \qquad D = \frac{W \times B}{P \times n}. \qquad P = \frac{W \times B}{n \times D}. \qquad W = \frac{P \times D \times n}{B}.$$

To calculate the strains on a crane by construction,

Let A B C represent a crane; A B being the suspension-rods; A C the jib; and B C the crane-post.

Weight, W, is assumed = 10 tons in the figure. With any convenient scale draw the vertical line A D, Fig. 4947, = W = 10 tons, or 10 divisions of the scales.

From D draw D E parallel to the jib until it cuts the line A B produced to E; from E draw the horizontal line E F and produce the line A D to meet it at F. The strains may be measured off by means of the scale as follows;—

Thrust on jib = E D = 19½ tons; strain on the suspension-rods = A E = 12½ tons. The crane-post may be considered as a beam fixed at one end C, and a weight = E F, = 11½ tons, applied at the other end B.

4947.

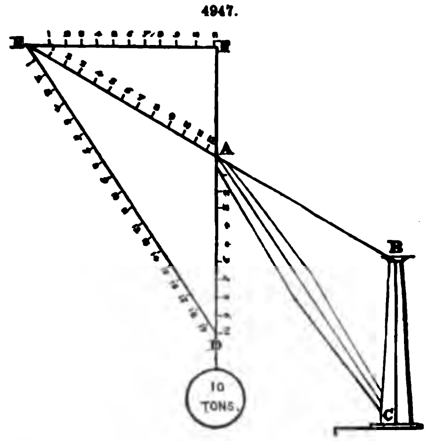
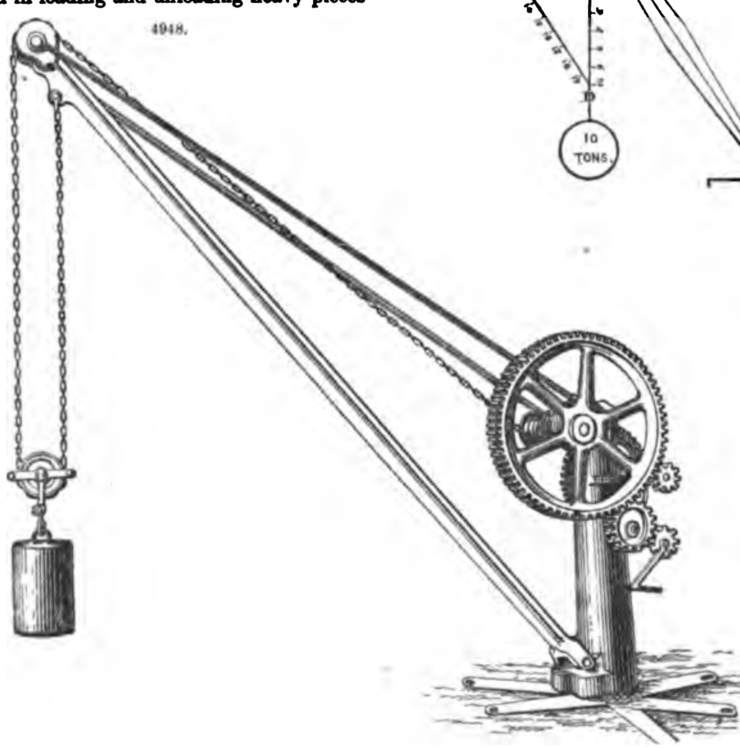


Fig. 4948 is of a jib-crane for shop purposes, made by Wm. B. Bement and Son, Philadelphia. It is used in loading and unloading heavy pieces

4948.



from planers and other tools, or for general lifting work. The machinery, including the jib, is all mounted on a strong metal post revolving on a stud attached to and supported by radial feet which are bolted to the foundation.

The spur-gearing which drives the reel is arranged with changes to suit the weight to be raised, and is driven by a winch.

The casing at the foot of the jib contains two rollers, which bear against the bottom of the supporting stand and prevent excessive friction when conveying a load. The framing, except the braces, is of cast iron throughout.

Tubular Wrought-iron Cranes.—Figs. 4949 to 4953 show the form and details of one of the tubular wrought-iron cranes erected by Sir Wm. Fairbairn at Keyham Docks, Devonport.

Six of these cranes are all of the same size and strength, and were calculated to lift a weight of 12 tons to a height of 30 ft. from the ground. Each of them is intended to sweep a circle of 65 ft. diameter, so that the projection of the jib was 32 ft. 6 in. from the centre of the stem, and the extreme height 30 ft. above the working platform. The cranes are composed of wrought-iron plates riveted together, and so arranged as to give the back or convex side an adequate degree of strength to resist tension, and the front or concave side, which is of the cellular construction, a corresponding power to resist compression. The form tapers from the point of the jib, where it is 2 ft. deep by 18 in. wide, to the level of the ground, where it is 5 ft. deep and 3 ft. 6 in. wide. From this point it again tapers to a depth of 18 ft. below the surface, where it terminates in a cast-iron shoe forming the toe on which the crane revolves. The lower or concave side, which has to resist a force of compression, consists of plates forming three cells and varying in width in the ratio of the strain; and on the other hand, the convex or top side, which has to bear the pull or tension due to the suspended weight, is formed of long plates connected together by a system of chain riveting. The sides are of uniform thickness throughout, the joints being covered with T-iron internally, and on the outside with strips or covering plates $4\frac{1}{2}$ in. wide.

The form of the jib, shown approximately in Fig. 4956, together with the point at which the load is suspended, is probably not the most favourable for resisting pressure. The crane, nevertheless, exhibits great powers of resistance, and may safely be considered as a curved hollow beam having one end immovably fixed, the force being applied at the other. Viewing it in this light, the strength is determined from the formula $w = c\,\frac{a\,d}{l}$, where w is the breaking weight at the end of the jib in tons; c the ultimate resistance of wrought iron to compression in tons a square inch; a the sectional area of the lower or cellular flange in square inches; d the depth in inches; and l the horizontal length or sweep of the jib in inches; the strength being supposed to be limited by the resistance of the lower or cellular flange to compression. From this formula it is found that it would require a load of 63 tons to break one of these cranes.

In the construction of cranes, whether of wood or iron, it is the usual custom to place the jib in an inclined position at an angle of about 40° or 50° with the stem, as in Figs. 4954, 4955, so as to obtain the greatest strength; in this position the extreme point from which the load is suspended has to be stayed or held in its place by oblique or horizontal tie-rods. With this arrangement it will be observed that, if the article to be raised is at all bulky, such as a large bale of merchandise or a marine boiler, it will be prevented from being elevated to the top of the crane by coming in contact with the diagonal stay or jib. Hence with ordinary cranes a considerable part of the height is practically unavailable. In the wrought-iron crane, however, Fig. 4956, this defect is obviated, since the curvature of the jib is sufficient to allow the article to be raised to the highest point to which the chain ascends.

Fig. 4949 is a sectional elevation of a 60-ton crane, showing the general arrangement and the well in which the crane is placed; and Fig. 4950 is a plan. Fig. 4951 is an enlarged vertical section of the lower portion of the crane.

Figs. 4952, 4953, are sectional plans of the crane at the level of the ground, and at the chain-barrel and gearing.

The crane consists of a rectangular wrought-iron tube A A, curved to a radius of about 46 ft., and tapering uniformly from 9 ft. deep by 5 ft. 6 in. wide at the level of the ground, where from the leverage of the crane the strain is the greatest, to 3 ft. 6 in. deep by 2 ft. wide at the point of the jib. From the level of the platform it is also tapered downwards to about 1 ft. 8 in. square at 23 ft. below the level of the ground, where it fits into a cast-iron shoe B working in a socket or step on which the crane revolves. The point of the jib is 60 ft. above the level of the platform, and sweeps a circle of 53 ft. radius; so that it will lift the heaviest load perpendicularly from a mean distance of 37 ft. from the quay wall, and to a height of no less than 85 ft. above low-water mark, and land it at 69 ft. from the edge of the quay.

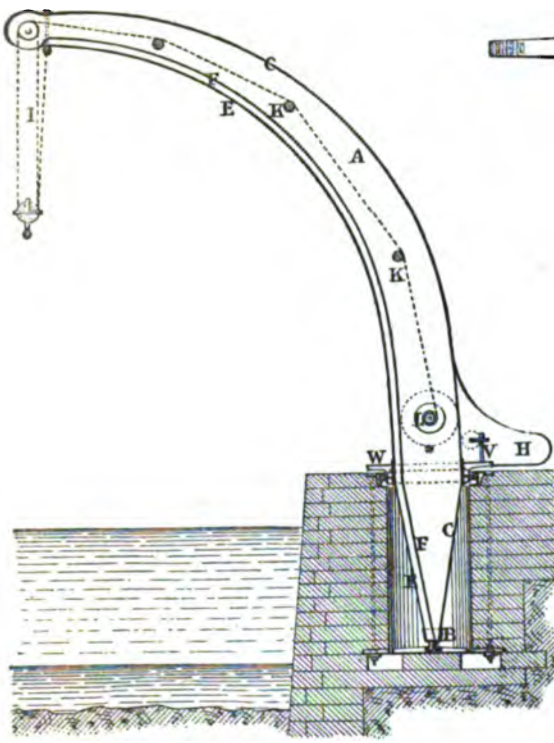
The crane itself is built on precisely the same principle as a tubular bridge, and may indeed be considered as a curved tubular girder inverted, the top side being the front or concave side of the crane, and the bottom side forming the convex or back part of the structure. Hence it may be described as composed of back plates, side plates, and cell-plates.

The back plates C, Figs. 4952, 4953, which, corresponding with the bottom plates of a tubular girder, have to resist a strain of tension, are made as long as possible to avoid joints, and are carefully chain riveted. They are $\frac{3}{4}$ in. thick and each half the width of the crane; and taking those on one side and beginning at the bottom of the well, the first back plate is 13 ft. 9 in. long; the second, which passes the point where the downward taper ends and the upward begins, is 13 ft. 6 in. long; the next is 12 ft. 6 in., followed by six others, each 12 ft. long, and these again terminated by a plate 15 ft. long which curves round over the pulley at the extreme point of the jib. These plates are covered externally by a long strip 8 in. broad and $\frac{3}{4}$ in. thick, extending the entire length of the crane and covering the longitudinal joint between the back plates. The cross-joints are placed alternately, and at each side of the crane there is a line of angle-iron connecting the back plates C with the side plates D, Figs. 4952, 4953. So that the sectional area of the back of the crane subjected to tension is, at the bottom 10·50 sq. in., at the platform 27·75 sq. in., at the point of the jib 12·00 sq. in.

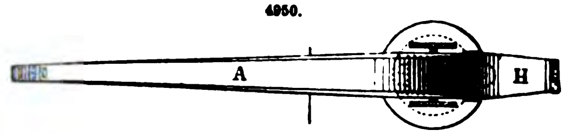
The sides of the girder are formed of plates 3 ft. broad at the outer edge or back of the crane,

riveted together with T-iron 4 × 2 × $\frac{3}{8}$ in. at every joint inside, and a strip outside, to give the necessary rigidity. Beginning at the toe, the first three plates are $\frac{3}{8}$ in. thick; the next three $\frac{5}{16}$ in.;

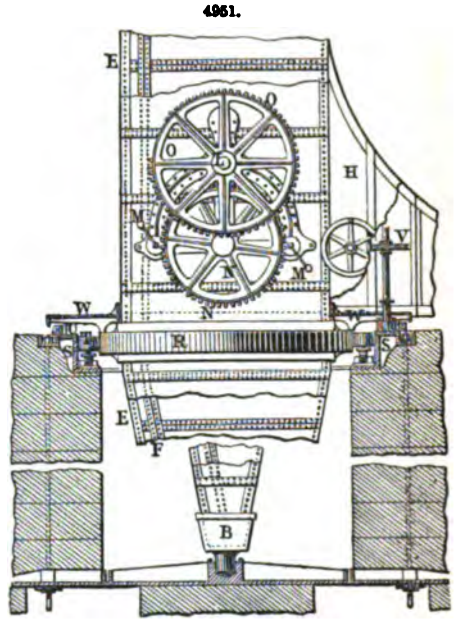
4949.



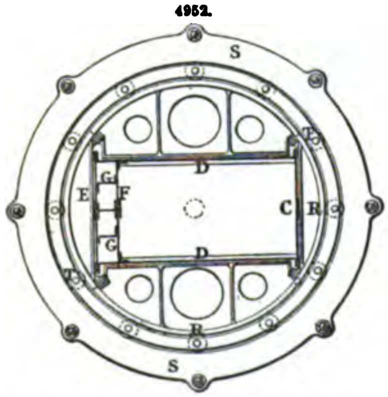
4950.



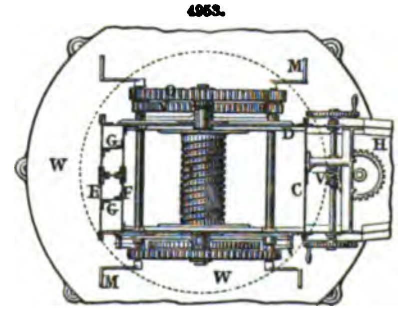
4951.



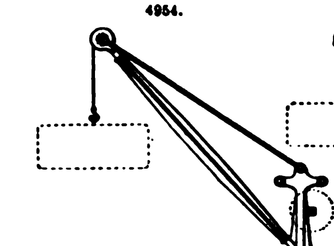
4952.



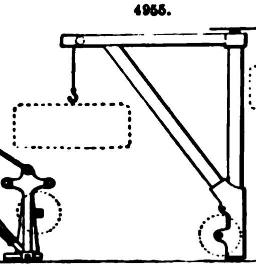
4953.



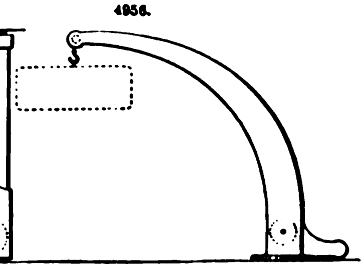
4954.



4955.



4956.



the next five, which have to resist the horizontal thrust against the cast-iron circle at the top edge of the well, $\frac{3}{8}$ in. thick; and the remainder $\frac{5}{16}$ in. thick.

The front of the crane is constructed with four cells, to resist the great strain of compression to which that part is subjected. The construction is shown in the sectional elevations, Figs. 4949 and 4951, and the transverse sections, Figs. 4952, 4953. The two series of plates E and F, which form the front and back of the cells, are composed of plates varying from 5 ft. to 7 ft. 6 in. long, and $\frac{5}{16}$ in. thick. Each of these plates is riveted by two angle-irons to the side plates D of the crane, the front plates E projecting beyond the side plates D, and the intermediate plates F being placed within the tube thus formed at a distance of 12 in. from the front plates E, so as to divide the tube into two. The narrow space between the plates E and F is further subdivided into four cells by three vertical plates G, parallel to the side plates D. Eight angle-irons connect the plates G with the plates E and F, and further strengthen the structure thus formed. The reason of this arrangement is that wrought-iron plates from their flexibility offer but a small resistance to compression in the direction of their thickness, as they bend or buckle with a comparatively small force. The five vertical plates, however, which form the sides of the cells, are placed in the position in which they offer a maximum resistance to compression, namely, with their width or depth in the direction of the strain; and the angle-irons and the plates E and F serve to keep them in position and give great rigidity to the structure. The centre plate G of the cells is $\frac{5}{16}$ in. thick, and the two remaining plates each $\frac{5}{16}$ in. thick. The sectional area of the concave or front part of the crane subjected to compression is therefore at the platform 62·58 sq. in., at the point of the jib 3483 sq. in.

Attached to the back of the crane is a tail-piece H or box of wrought iron, containing cast-iron weights acting as a counterpoise to the jib. The chain I is attached to the crane by a bolt and nut at the point of the jib, and passes round four pulleys, two movable and two fixed in the end of the jib; it is then conducted down in the interior of the jib over three rollers K to the barrel L, which is also in the tube near the ground. On each side of the crane a strong cast-iron frame is fixed for receiving the axles of the spur-wheels and pinions. Four men, each working a winch M of 18 in. radius, act by two 6-in. pinions upon a wheel N, 5 ft. 3$\frac{3}{4}$ in. diameter; this moves the spur-wheel O, 6 ft. 8 in. diameter, by means of an 8-in. pinion, and on the axle of the former the chain-barrel L, 2 ft. in diameter, is fixed. Hence the advantage gained by the gearing will be

$$\frac{W}{P} = \frac{18 \times 63{\cdot}75 \times 80}{6 \times 8 \times 12} = 158;$$

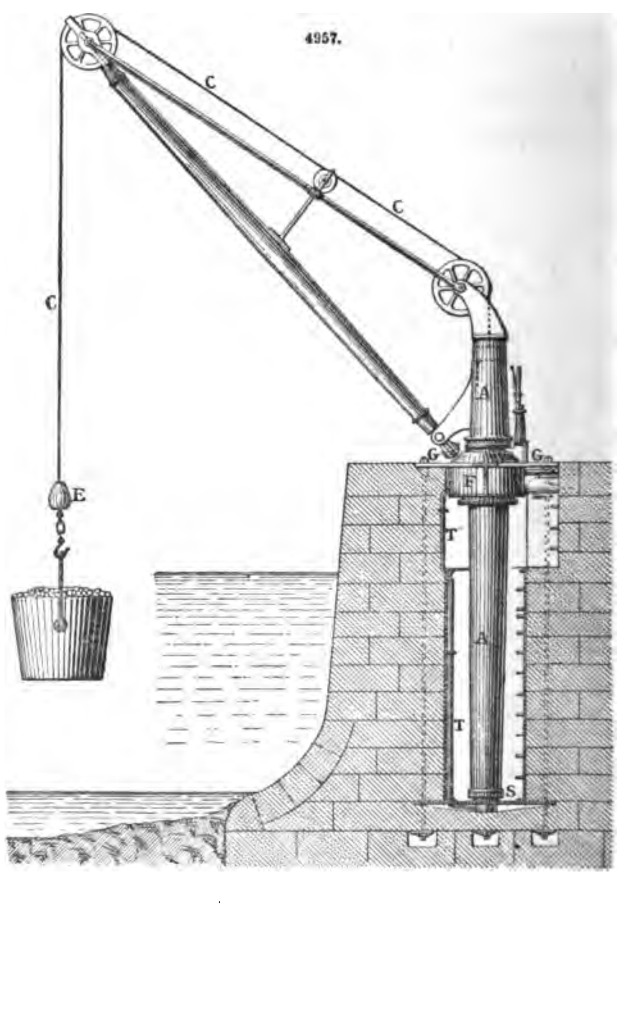
or, taking the number of cogs in each wheel,

$$\frac{W}{P} = \frac{18 \times 95 \times 100}{12 \times 9 \times 10} = 158;$$

and as this result is quadrupled by the fixed and movable pulleys, the power of the men applied to the handles is multiplied 632 times by the gearing and blocks. A brake-wheel, Fig. 4953, 5 ft. 2 in. diameter, is fixed on the other end of the spindle of the spur-wheel N; and the power applied at its circumference is accordingly multiplied about 100 times by the gearing and blocks.

At the level of the ground the crane is firmly fixed in a strong cast-iron frame R, Figs. 4951, 4952, the outer edge of which is a circle of 11 ft. 3 in. diameter; and on the edge of the well a similar ring S is imbedded in the masonry and secured by long holding-down bolts, leaving a space of 10 in. all round between it and the inner ring R. In this space a number of strong cast-iron rollers T are placed, 10 in. in diameter, to prevent friction and facilitate the movement of the crane as it revolves round its axis. Upon the cast-iron ring S on the quay wall is fixed a circular rack U, composed of cogged segments bolted together, into the teeth of which a small pinion works, whereby the

4957.

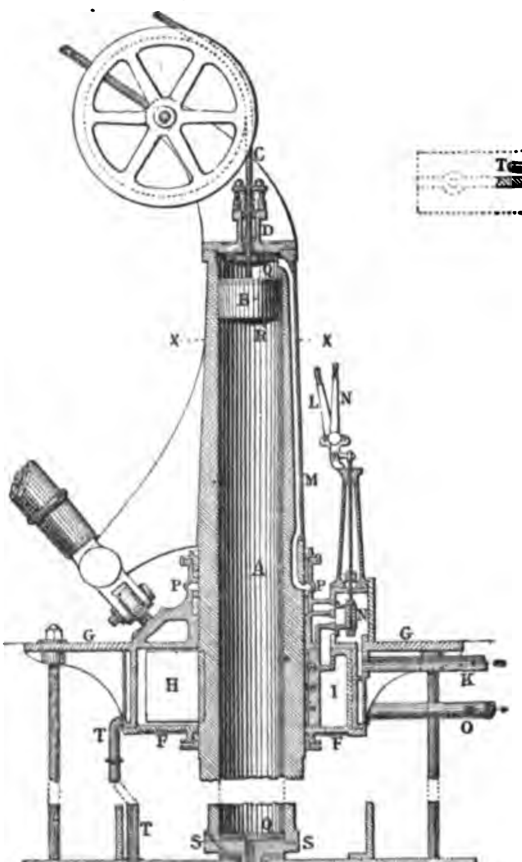


crane is made to revolve. This pinion is worked by a worm and wheel V placed in the counterpoise box H; and two men are sufficient to move round the crane with 60 tons suspended from the extreme point of the jib. In working the crane the men stand upon a cast-iron platform W attached to it a few inches above the level of the ground.

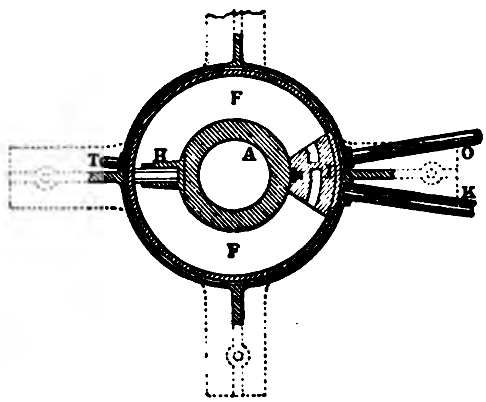
Fig. 4957 is an elevation of a very ingenious direct-acting steam-crane, designed by Robert Morrison, of Newcastle-on-Tyne, in which the steam-cylinders, gearing, and other complications of the ordinary steam-crane, are done away with; and the crane-post is made the steam-cylinder, fitted with a piston having a flexible piston-rod of wire rope, which works steam-tight through a stuffing box at the top and passes over two pulleys, forming itself the chain for lifting the load.

Fig. 4957 is a side elevation of a 2½-ton Morrison crane; Fig. 4958 a vertical section of the crane-post to a larger scale; and Fig. 4959 a sectional plan.

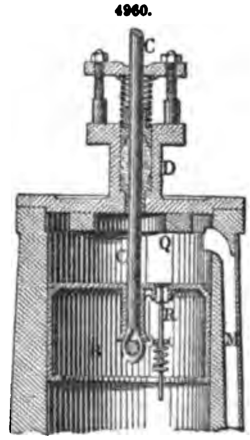
4958.



4959.



4960.

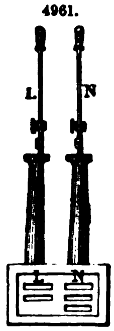


The crane-post or cylinder A of cast or malleable iron is made in one length, or in two or more pieces bolted together as may be convenient, and bored out to a size suitable for the weight to be lifted and the pressure of steam to be used. The length of the bored portion of the crane-post corresponds with the height of lift required. Within the cylinder works the piston B, which is firmly secured to the end of the flexible piston-rod or wire rope C. This piston is made with a wedge-shaped packing ring, as shown in the enlarged section, Fig. 4960, so that when the pressure of steam is upon it the packing expands and makes it steam-tight; but as soon as the pressure is removed the packing contracts, so that the piston works freely in the cylinder and the weight of the rope is sufficient to overhaul it. The wire rope C works steam-tight through a stuffing box D at the top of the crane-post, and passes over the two pulleys, one on the top of the crane-post and the other at the extremity of the jib. At the end of the rope is fixed the cast-iron ball E, containing a volute spring to which the hook is attached for the purpose of relieving the crane and rope from any abrupt strain when beginning to lift the weight. The wire rope is much safer than a chain, since it is not liable to the sudden fracture often occurring in crane chains, nor is it affected to the same degree by the temperature of the atmosphere. The stuffing box D through which the wire rope works is fitted with a conical gland, pressed down by a spiral spring, so that the packing is always kept well pressed up round the wire rope, without the necessity of screwing up, as is the

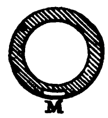
case with ordinary stuffing boxes. The turning-round cylinder F, Figs. 4958, 4959, for swinging the crane round, is cast on the under side of the bed-plate G and forms part of it; it is truly bored and fitted with a rectangular metal-packed disc or radial piston H secured to the outside of the crane-post A. A segmental block I forming the abutment is bolted to the inside of the cylinder F, and made steam-tight next the crane-post by metallic packing and springs.

In working the crane, the steam is admitted from the steam-pipe K through the lifting valve L, Fig. 4970, by means of the handle, Fig. 4961, and passes up through the port M in the crane-post A, Figs. 4958, 4962, to the top of the post, where it presses on the lifting piston B and raises the load. The valve L is then closed, and the steam retained in the cylinder A, so as to hold the weight suspended; while the crane is swung round right or left by admitting steam through the turning valve N to either side of the turning piston H. The handle L is then reversed and the steam above the piston B allowed to escape through the exhaust-pipe O, and the weight is lowered to the required position fast or slow as desired. There is a passage round the stuffing box P for the purpose of admitting the steam into the port M at any position of the crane; this passage is packed at top and bottom with a lantern brass between, so that the top gland tightens both packings at the same time. It was apprehended at first that on account of the expansive action of the steam there would be some difficulty in starting and stopping the crane instantaneously, but no such difficulty exists in practice. The lifting valve L, shown enlarged in Figs. 4963, 4964, is made with oblique edges, so that the lifting can begin gradually and stop instantly. The turning-round valve N is also made in the same way; and for stopping the crane suddenly when turning round it is only requisite to admit the steam to the opposite side of the turning piston H; this not only stops the crane at once, but also forms a cushion for the piston. Provision is further made at each end of the lifting cylinder A, as well as in the turning-round cylinder F, for preventing accident in case the steam should not be shut off at the proper time, by placing a ring of india-rubber Q, Fig. 4958, to form a cushion for the piston at each end of the cylinder, so that no damage can be done.

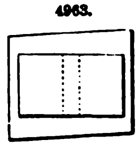
4961.



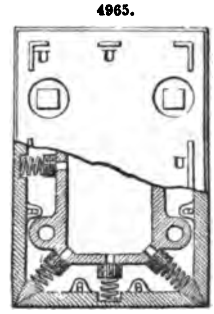
4962.



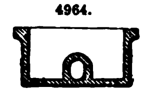
4963.



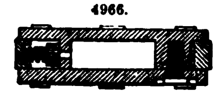
4965.



4964.



4966.

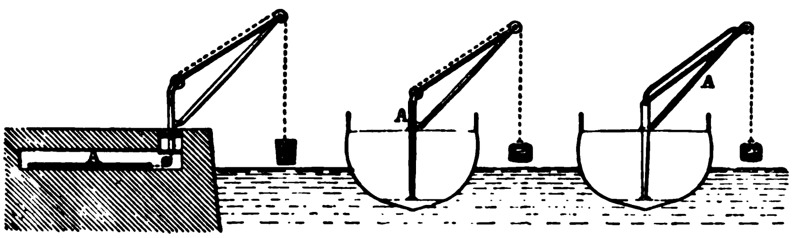


The turning-round cylinder F is cased and constantly surrounded with the exhausted steam, as in Figs. 4958, 4959; this keeps it hot and prevents condensation. The crane-post A may be covered with felt and wood to keep it warm. It might be supposed that in working the crane the steam would condense so rapidly in the crane-post that no weight could be held suspended steadily for any length of time; but in practice no perceptible change is observed in the position of the weight if left suspended for twenty minutes without any steam being admitted into the crane-post; there is indeed no perceptible condensation of steam, and no more power is required to lift 2 tons than a pressure of 2 tons upon the area of the piston, with the usual allowance for friction. The crane is blown through at starting in order to clear it of any water that may have condensed in it, and is thus heated so that it is not found requisite to blow through a second time as long as it continues at work. The blowing through is effected by means of the small mitre-valve R placed in the piston B, Fig. 4960, kept closed by a spiral spring; but when the piston comes to the bottom of the crane-post the valve is opened and allows the steam to pass through the hollow step S of the crane, Fig. 4958, blowing out any water through the pipe T; the crane-post is thus warmed down to the very bottom. The under side of the lifting piston must communicate with the atmosphere, in order to enable it to work satisfactorily, otherwise in lowering the weight a vacuum would be formed below the piston which would retard the lowering and render it impossible to overhaul the piston and rope when the weight was removed; and as a direct communication between the cylinder and the atmosphere would cause the cylinder to be filled with cold air after every lift, entailing a great loss of heat, to obviate this the blow-through pipe T is connected to the casing of the turning cylinder F, so as to allow the exhaust steam from the casing to follow up the piston B in lowering the weight. The turning-round piston H, shown enlarged in Figs. 4965, 4966, is made with four brass packing bars pressed up by springs, with a V piece inserted in each of the four corners and kept up by a spring; these corner pieces are made of white metal, and being softer than brass the point will wear as fast as the sides of the packing bars, and thereby keep the corners always tight. This piston is made independent of the rest of the crane, the packing bars being fitted and ground into their place, springs put in and the cover bolted down before the piston is put in its place; the bolt-heads are sunk in the cover, and the fitting strips U carefully planed and well fitted into the radical forked arm H, Fig. 4959, which is planed out to embrace the piston. This arm is made of malleable iron and securely bolted to the crane-post A; it is made ½ in. shorter at each end than the cylinder F, so as to allow the crane-post to work up or down without jamming the piston in the cylinder. To examine or repair this piston it is only requisite to unscrew and lower the cylinder-

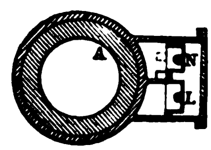
cover, and the piston can be drawn down from its place and removed entirely. The well in which the crane-post A works is kept quite dry by a cast-iron lining extending entire to the level of high water, Fig. 4957, where a recess is cut out on one side to allow of going down into the well to examine and grease the crane-step S at the bottom.

A crane of this construction, with a lift of 22 ft. and a radius of 20 ft., will lift, swing round, discharge, and swing back to reload three times a minute, or will discharge three tubs of coal of 2 tons each in one minute, or a greater quantity if the tubs can be filled fast enough. In addition to the expedition of these cranes, the smoothness of their motion and the absence of any jerking, such as takes place with chains and the ordinary gearing, are of importance, preventing any undue strain upon the foundation, or the sudden breakage of chains or other parts of the crane. Smoothness of motion is obviously of great advantage when cranes are used on board ship, for it is well known that the unsteady motion of the present cranes is very injurious to the decks; this is so much the case that it is impossible to keep the decks water-tight for any considerable time; and when covered with lead or sheet iron to prevent the water getting through, the decks and beams are eventually so much injured by the constant jerking and vibration caused by the ordinary steam-cranes, that repairs are required more frequently and at a greater expense than would otherwise be the case.

4967. 4968. 4969.



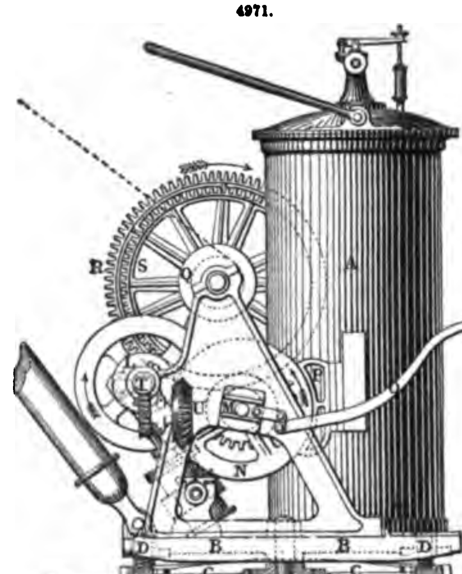
4970.



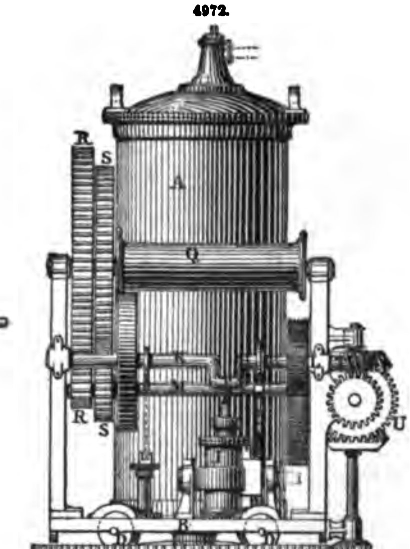
Another arrangement of this steam-crane is shown in the diagram, Fig. 4967, intended for situations where there is not sufficient depth for the crane-post, or where from other causes the post cannot be carried down. In this arrangement the lifting cylinder A, shown black in the diagrams, is laid horizontally below the surface of the ground, and the rope is guided to the post by a pulley; the cylinder may be close to the surface, and the rope then pass over a pulley at the stuffing box and down at an easy angle to the pulley below the crane-post. This arrangement is also suitable for warehouses, the rope leading to the different floors; or the cylinder may stand upright in the warehouse and have a handle on each floor for working it. Figs. 4968, 4969, represent modifications of the crane proposed for application on board ships. In Fig. 4969 the jib A is made of malleable iron, and forms the lifting cylinder; this arrangement is intended to be used on board vessels where it is not desirable that the steam-cylinder should go below the deck. There are also several other situations where this mode of working by the application of a direct-acting steam-cylinder with wire-rope piston-rod might be adopted with advantage, such as for opening and closing dock gates and bridges.

The steam-crane, Figs. 4971 to 4973, was designed by J. Campbell Evans for use on board

4971.

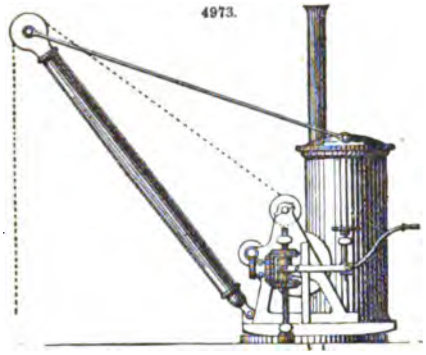


4972.

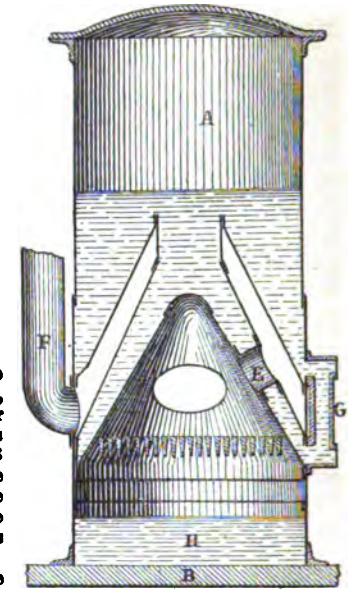


steam-vessels, and the chief points to be aimed at were compactness, facility of fixing, simplicity in the mode of working, and durability.

4973.



4974.

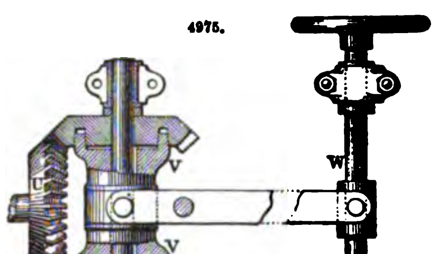


To obtain these advantages, in the present steam-crane the boiler A is placed as close as possible to the crane, and revolves with it; and by making the top of the boiler of cast iron with lugs for attaching the tension-rods, it serves the double purpose of boiler and crane-post. The bed-plate B upon which the crane and boiler are placed is fixed to the foundation plate C by a centre bolt, which bears all the upward strain; the downward pressure is taken by the rollers D running on the foundation plate C; this plate is solidly bedded on timber laid on the deck of the vessel.

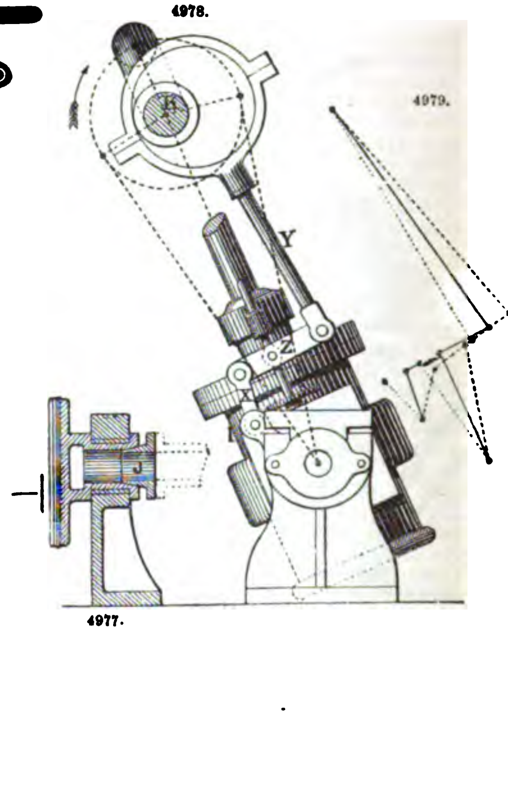
To avoid upright tubes and horizontal tube plates, the heating surface of the boiler A is arranged in cones, Fig. 4974. The first cone or fire-box is exposed to the direct radiation of the fire, after which the heat passes through the opening E nearly opposite the fire-door into the space between the second and third cones, where it is absorbed by the water-spaces on either side, and passes round to the funnel F opposite. In this way a sufficient heating surface is obtained without any horizontal surfaces in the boiler for deposit to accumulate upon. The two angles or bottoms of the water-spaces are below the direct action of the fire, and are connected by pipes G to allow for the circulation of the water, provided with plugs and cocks for cleaning. The water-tank H is placed under the boiler, this position serving to heat the feed-water and to preserve the cast-iron bed-plate B from danger of fracture by the heat of the fire.

The crane is worked by a single oscillating cylinder I, shown enlarged in Fig. 4978, supported by brackets on the bed-plate B. The joints for the steam and exhaust pipes at the trunnions are made tight by gun-metal cones J, Fig. 4977, fitted to the trunnions and held by studs in the

4975.

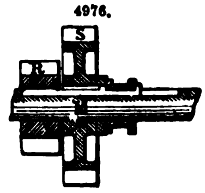


4978.



4977.

4976.



brackets; when these have become polished by working, the wear upon them is very slight, and this construction has been found very suitable for the rough treatment to which cranes are usually subject. On the crank-shaft K is a friction-wheel L, Figs. 4971, 4972, kept continually revolving by the engine. On the second shaft M is another friction-wheel N, which can be moved by the lever O into gear with the driving wheel L, or by an opposite motion of the lever can be pressed against the brake P, or when lowering can be held between the two. The other end of the shaft M carries pinions gearing into wheels on the shaft of the chain-barrel Q. There are two pairs of wheels and pinions, R and S, for varying the speed according to the weight to be raised; the pinions are thrown in and out of gear by a sliding key, enlarged in Fig. 4976, instead of the ordinary clutch; by this means the width between the frames that would be required for moving the ordinary clutch is saved.

A principal difficulty experienced in steam-cranes for ship purposes is in the arrangement of the turning gear, so that when the vessel leans over to one side, the crane shall be powerful enough to swing the weight and yet not cause a sudden start or shock to break the gear. In this crane a coned friction-clutch is used, Fig. 4975, to allow a slip at first and to start the weight gradually; and the arrangement of the foundation plate C of the crane admits of a much larger spur-wheel than usual being employed to bring up the power. On the crank-shaft K is a worm T working into a worm-wheel on the shaft of the bevel-wheel U, Figs. 4972, 4975, which gears into the two bevel-wheels above and below: as these are kept constantly revolving by the engine, the crane can be moved round either way by raising or lowering the coned clutch V by the lever and screw W. The lifting lever O and the screw W being close together, Fig. 4973, the two operations of lifting and turning the weight are easily managed by one man.

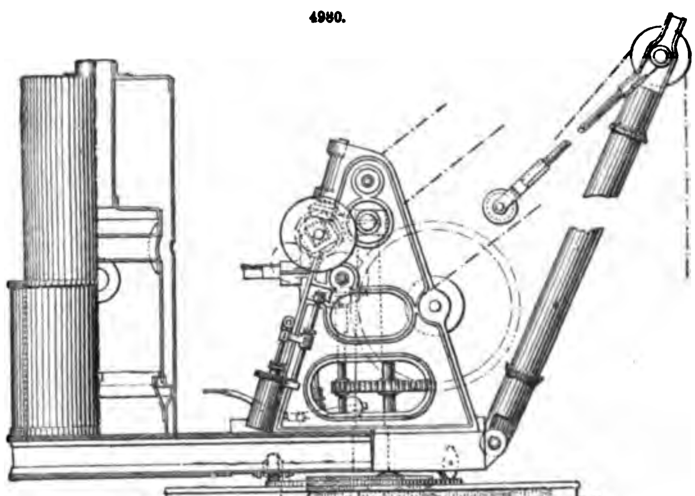
The valve motion of the oscillating cylinder I, Fig. 4978, is designed to compensate for the oscillation of the cylinder without the use of sweeps and guides. A radius rod X is centred on the cylinder bracket and connected to the eccentric rod Y by a link Z, to which the valve-rod is attached by a pin. The link Z combines the vibrations of the eccentric rod Y and radius rod X, so that at the point where the valve-rod is attached the curve described by the radius rod compensates for that described by the eccentric rod in such a degree as to bring the valve-rod into the curve it would naturally be made to describe by the oscillation of the cylinder, as shown by the diagram, Fig. 4979.

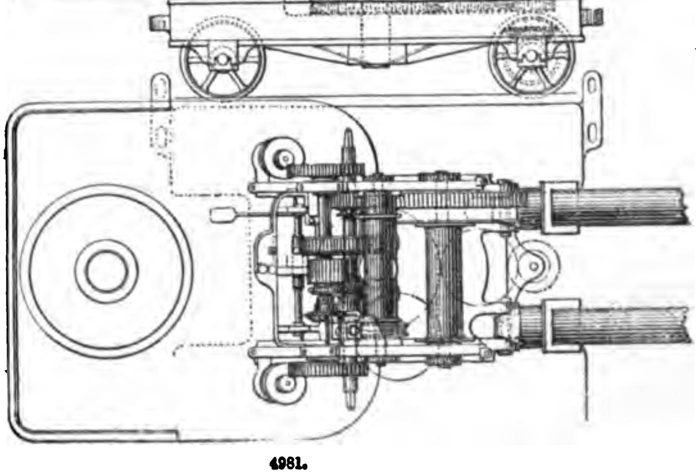
Figs. 4980, 4981, are an elevation and plan of a locomotive steam-crane, constructed by Appleby Brothers, London, a type of crane used extensively for facilitating the loading and unloading of goods at railways, harbours, and so on.

The carriage is generally in one massive casting of suitable form to take the central post, which is of wrought iron, and horns are provided with bearings for the travelling wheels which are placed inside the bed for narrow gauge and outside for wide gauge. The top of the carriage is recessed for a spur-wheel fitting on the column, and made fast or loose with it, and this to a raised roller path truly turned on the outer edge of the recess.

The superstructure of the crane consists of a base-plate revolving on the central column fitted with three friction-rollers, two being placed directly below the jib and one at the back to take the weight of boiler and tank. A

4980.





4981.

pair of A frames are erected on this base-plate with all the bearings and fittings for the machinery and engines. A wrought-iron feed-water tank of the depth of the revolving base is bolted on to it and carries the boiler a considerable distance away from the centre of the crane-post, forming a counterbalance to the load to be lifted, as well as a foot-plate for the driver. The boiler is vertical, the internal fire-box being fitted with two cross water-tubes; this form of boiler, although not the most economical as regards fuel, is preferred to multitubular ones as it has often to be worked with the worst kind of water, with but little attention, and a stoppage is considered of far greater moment than strict economy in fuel; but the cranes are made with multitubular boilers for countries where fuel is expensive. The boiler is fitted with all the usual steam and furnace requirements, including an extra lock-up safety-valve; and a small extra steam feed-pump, to feed the boiler if the crane is not running, is sometimes added.

The crane is fitted with a pair of direct-acting steam-cylinders placed, slightly at an angle, one on the outside of each side frame, the crank-pins being fitted into a pair of balanced disc-plates—the engine-shaft between the side frames carries a bevel-wheel made fast or loose on the shaft by a toothed clutch for driving an oblique worm-shaft gearing into a tangent-wheel on the derrick chain-barrel for raising or lowering the jib, the worm-wheel securely locking the jib at any desired radius. On the middle of the crank-shaft a wide spur-wheel is keyed; this wheel gears into a narrow wheel below it on a weigh shaft which has a small crank-pin at each end equal to the stroke of the side valves; this narrow wheel can be moved by a hand lever, laterally, about 4 in. on a spiral feather, thus reversing the valves for running the engines in either direction; this arrangement is found to answer the purpose and to give more durability than an ordinary link-motion. On the left-hand side of crank-shaft are placed a pair of spur-wheels gearing into wheels on the counter-shaft below; one pair of these wheels are of equal and the other of unequal diameters, either pair being made drivers by a double toothed clutch; the ends of counter-shaft are provided with squares for ordinary handles to work the crane by hand if desired. On this shaft is also fitted a set of bevel-wheels and double friction-cones for giving motion to the slewing and travelling motions; and this shaft having two speeds imparted to it from the engine-shaft will consequently communicate two speeds to the slewing and travelling motions.

The motion from this set of wheels is carried by a vertical shaft and train of wheels to the spur-wheel on column. This spur-wheel on the column is of double the depth of the pinions gearing into it; the pinions are placed at different heights so that the pinion revolving round the spur-wheel in slewing clears the fixed pinion driving the travelling gear. When it is desired to travel the crane, the crane body is fixed to the carriage, and the wheel then revolves on the crane-post and drives the travelling motion.

The friction-cones are put in and out of contact by an eccentric lever, and can be thrown into contact whilst the engines are running, putting the jib gradually in motion, without shock; when it is desired to arrest its motion the cones are reversed, and they then act as a brake.

The lifting motion is conveyed from the counter-shaft by a pinion sliding on a feather in and out of gear with a spur-wheel on the barrel-shaft; in lowering, this pinion is drawn out and the descending load is controlled by a strap-brake actuated by the foot of the driver. Should the driver desire to leave the load hanging for any time, the foot-lever is fitted with a pawl and ratchet to hold the load when the foot is removed from the lever. The slewing motion being given by reversing friction-cones, it can be put into action while a load is being lifted or lowered, saving much time.

When the maximum loads are lifted, the power of lifting is doubled by a single block, and the chain looped up to the jib head; this arrangement being adopted because the majority of the loads are light and require handling quickly.

Cranes of this construction are made of various powers, the proportions being modified to suit the duty for which they are required.

The crane-posts are made of wrought iron, and the travelling wheels are chilled on the face. There is ample margin of strength throughout, and generally the details of construction of Appleby's cranes have been well considered and carefully worked out.

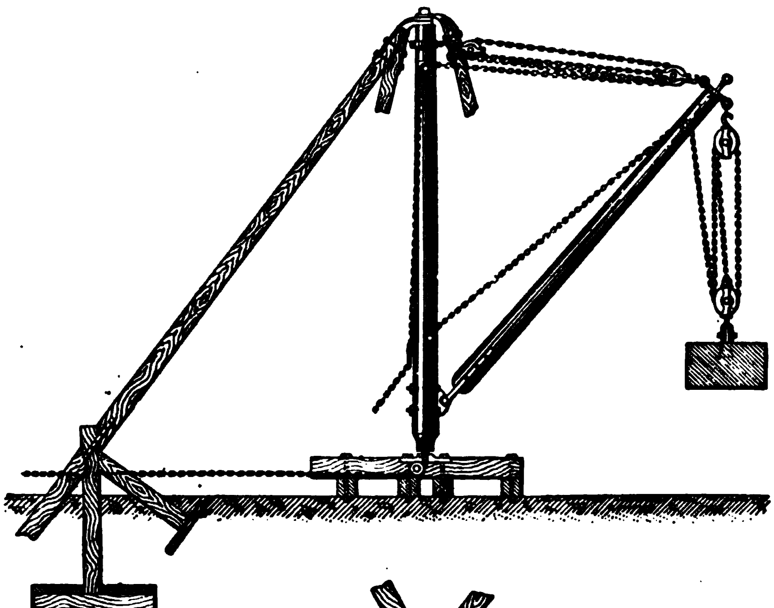
The cranes most frequently employed in America for building purposes are of two kinds, those which consist of a mast and movable jib, and those in which the jib is fixed at a certain angle with the mast. In the former system the mast is held by three pieces of timber, having at their upper ends a collar which passes over a kind of gudgeon on the top of the mast, Figs. 4982, 4983. The jib is jointed at its lower end to a piece of iron bolted to the mast, so that it may turn about a horizontal axis, or be inclined to a greater or less angle. It is moved by a chain, which, after passing over two pulleys fixed one at the top of the mast, the other at the upper end of the jib, is brought down by the side of the mast and then carried away horizontally to a steam-windlass. A third pulley hanging from the head of the jib supports the weight to be raised by means of a tackle-block. The hoisting chain passes down the jib and into the lower end of the mast, which is here hollow, and down through the pivot and bed, from whence it is carried away horizontally to another steam-windlass. Cranes of this kind are employed on the Illinois Canal to ship the stone from the Lemount quarries.

Of the second kind we may cite one example used in the work of enlarging the Capitol at Washington and subsequently at the Cabin John bridge, aqueduct of the Potomac. In this crane, Figs. 4984, 4985, the jib is fixed at its lower end in a shoe or socket bolted to the bottom of the mast. The length of these two pieces, mast and jib, is 50 ft., and they form a nearly equilateral triangle with the 1-in. iron rod which joins their two extremities. The mast is 13 in. by 13 in., and the jib 10 in. by 10 in. scantling. The mast is held by wire ropes. Six pulleys, 13 in. in diameter, are used, two at the head of the mast and jib respectively, and two others capable of oscillating about the same points; the two latter are simply suspended in space by ropes, but are held together by a short connecting chain upon which the lifting hook is fixed.

There are two distinct sets of ropes, each connected with a windlass, and one of which ends at

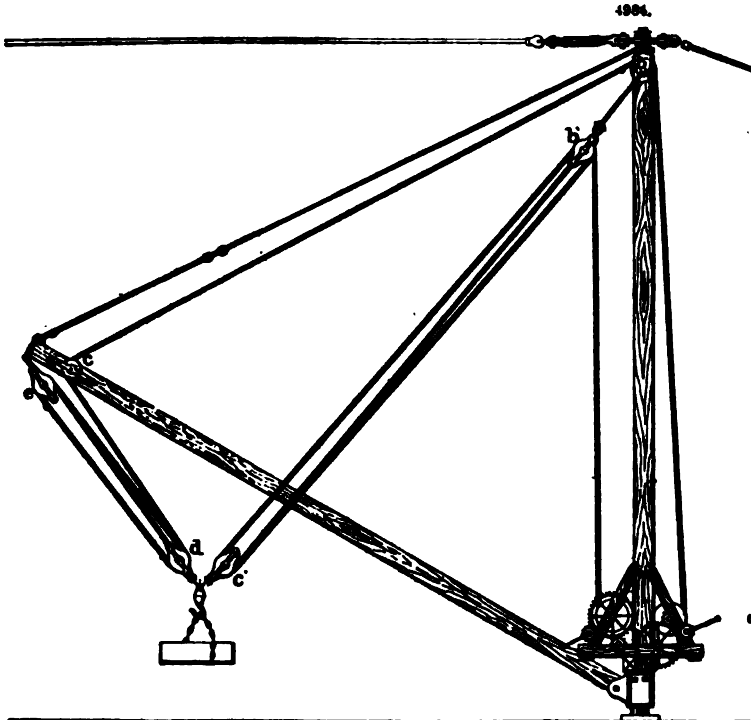
the oscillating pulley b' of the mast after passing twice over this same pulley, and also over one of the free pulleys c'; the other, after passing over the two fixed pulleys b and c, passes twice over

4982.



4983.

4984.



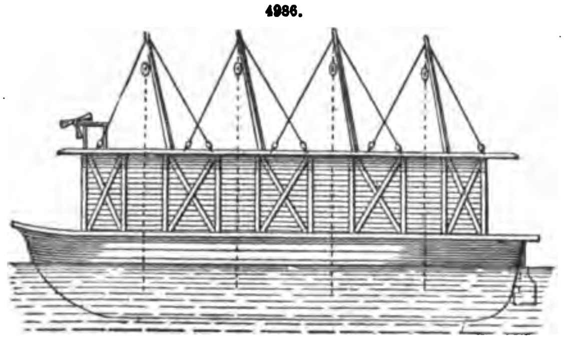
4985

the second free pulley *d* and the oscillating pulley *e* of the jib, and is finally brought back and fixed to the free pulley *d*. It will be seen by referring to the figure that by hauling the rope on the right and letting go the other at the same time, the weight will be carried to the left, and the reverse; and that if both are hauled at the same time the weight will be raised. Hence it follows that by communicating to the two windlasses unequal and properly-combined velocities, the weight may be removed to any spot in the vertical plane of the crane. In nearly all cases the crane is turned round by hand, though the windlasses are worked by steam-power, and for this purpose a rope is fixed to the head of the jib.

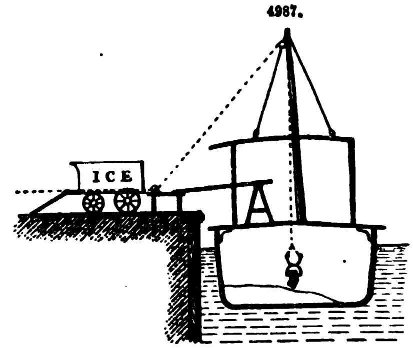
The crane used for unloading coal on to the quays of New York consists essentially of an upright standard or bearing-post and an inclined arm or jib, the upper ends of which are connected by an iron rod. The upright portion is simply scarfed upon one of the posts on the quay. The jib rests upon a hinge against one side of the upright shaft, the north, for instance. At the upper end of the jib is a pulley, over which a rope passes having at one end a receptacle for the coal, which is shovelled in by a man on board the vessel; the other end of the rope is carried away to the north of the mast and passed under a second pulley fixed on a level with the ground, and attached to the horse which moves the lifting apparatus during the standing still of the coal-cart. Left to itself, the movable triangle, which we suppose at first directed towards the vessel, would make a quarter turn towards the north and bring the load of coals, previously drawn up to the required height, directly over the cart which is to receive it; it is necessary therefore to keep the crane in its place during the operation of lifting. For this purpose another rope is fixed to the upper end of the jib and carried away southward to a post, around which it is wound in one or two turns. A man stationed at this post lets go the rope when it is time for the crane to turn, and pulls the crane back by it again when the load has been emptied into the cart.

The New York ice cranes, Figs. 4986, 4987, are equally simple. They are composed of a single

4986.



4987.

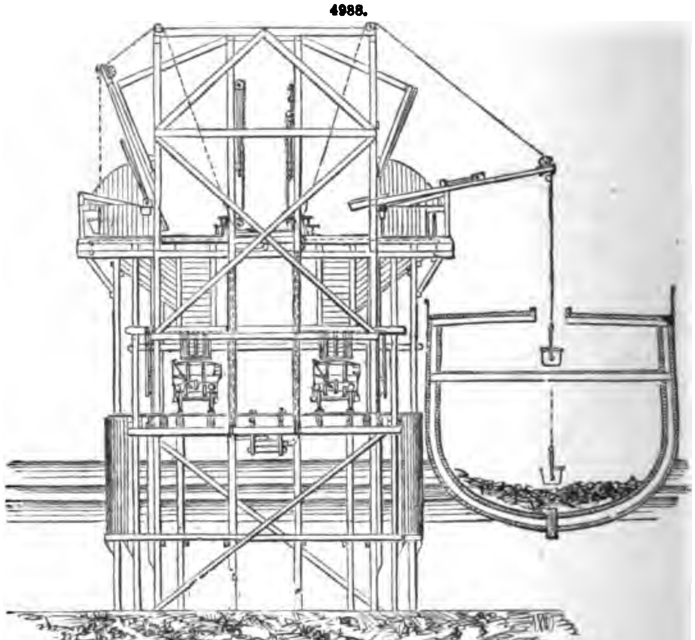


standard, kept upright by stays and furnished with a pulley. The ice is lifted by a lazy tongs attached to the hauling rope, which is so arranged as to swing it immediately into the ice cart, Fig. 4987.

The arrangement of the ballast-cranes erected on one of the jetties of the Tyne docks for the delivery of ballast is shown by Figs. 4988, 4989. They are operated by hydraulic power. The rate of delivery when the machinery is in full work is 50 tons an hour for each crane. With the exception of the use of hydraulic power instead of steam, the arrangement of these cranes is nearly similar to those which have been for some time in use at Hartlepool.

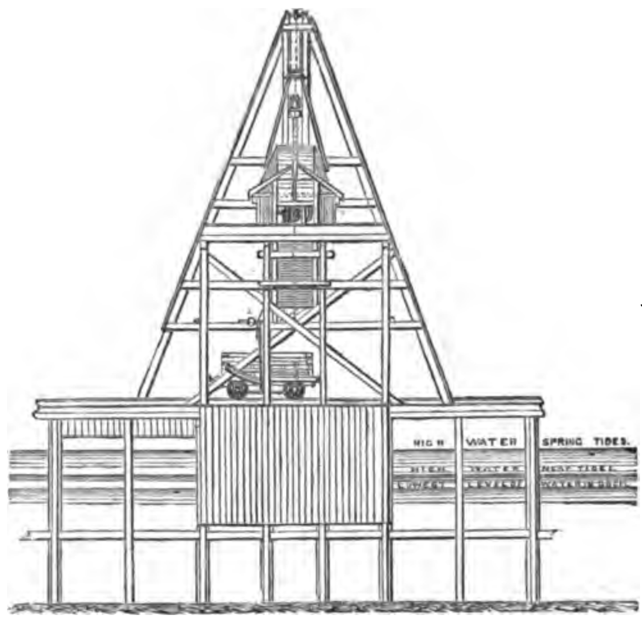
The gins, Figs. 4990, 4991, employed

4988.



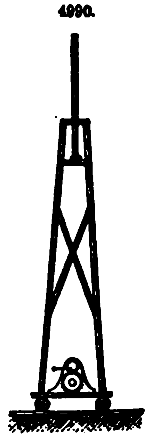
at Cincinnati for raising the stone slabs with which the fronts of the houses are covered, consist of two poles slightly inclined, and supporting another at their upper ends. These, with the windlass, rest upon a bed with four wheels. The upper pole carries a pulley at about 65 ft. above the ground. It is held by two ropes placed obliquely in the ground behind, and supported by a spur. The stones are held by a special appliance, in which two screws press against the faces of the slab.

4989.

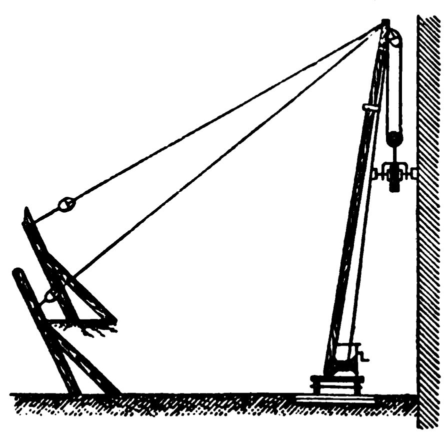


The boom-derrick represented in Figs. 4992, 4993, is commonly employed in America, especially in bridge-building. The boom, which consists of two twin pieces, extends a little beyond the back of the mast, and this end of the boom is tied to the top and bottom of the mast by two strong wire ropes. The portion of the boom over which the traveller works is supported by ties from the top of the mast. The weight is suspended to this traveller through the medium of a pulley. There are besides three fixed pulleys, two upon the boom near the mast and one at the end. An endless rope goes from one of the windlasses to the other, passing over not only the three fixed pulleys, but also the two rollers of the traveller, and, in the space exactly in the middle of this symmetrical circuit, the pulley, to the frame of which the lifting hook is attached. By communicating to the two windlasses, or allowing them to take unequal velocities, the traveller is moved forward or backward, and at the same time the weight may be raised or lowered at pleasure. When the derrick has to be turned far round, it is better to lead the ropes down through the pivot made hollow for that purpose, as in the case explained above.

4990.



4991.



Most of the appliances employed in the American ports for removing the masts of ships are of the nature of this derrick. In these cases the boom is swung to its mast by the middle, and the weight is balanced by a counterpoise. These balance derricks are sometimes employed in situations where it is inconvenient to fix guys.

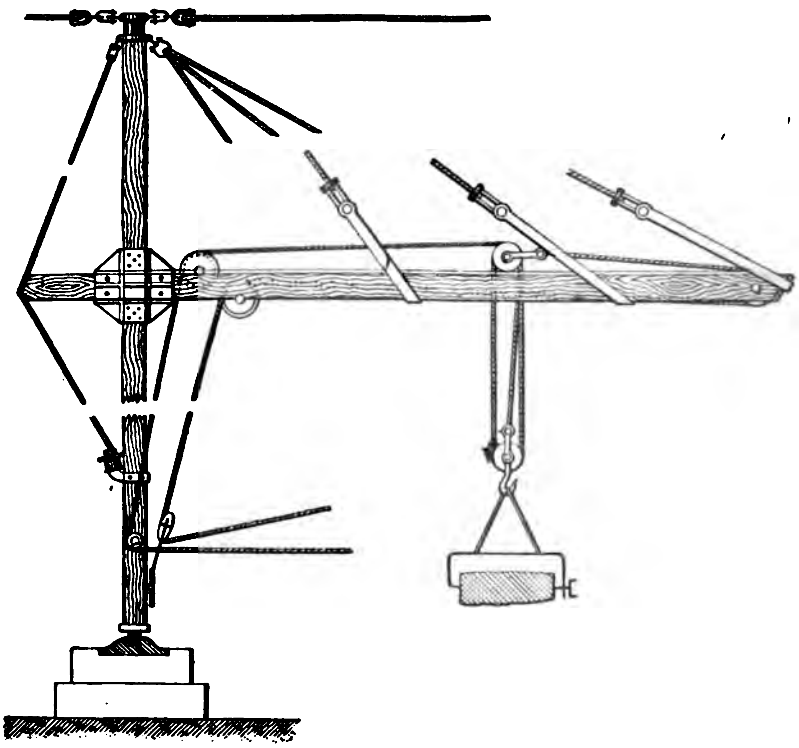
Movable derricks, or those which are capable of transporting their load from one spot to another otherwise than by merely revolving on their axes, differ from those we have described only in the manner of their erection. The mechanical principles upon which they act are in all cases the same. Of movable derricks, the floating are the most important.

The common characteristics of these machines are lightness, simplicity, and cheapness, both of construction and working. Instead of heavy and expensive machines, these are often the simplest appliances made on the spot with two or three pieces of wood and a few bits of rope. As we have said above, they are always turned round by hand, and the intermediate time of the man or the men set to do this may be employed in other work.

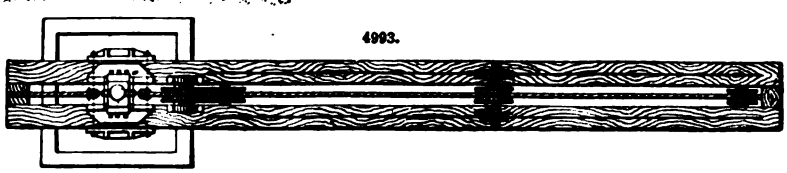
Figs. 4994 to 4996 are views of a substantially-built 15-ton crane with timber framing, arranged with compound braces, by Wm. B. Bement and Son, Philadelphia. The reel or winding drum is driven by spur-gearing operated by a winch. The traversing movement is attained by means of

the gearing upon the beam, which, through a chain indicated in the dotted lines, moves this gearing out or in upon the top beam.

4992.



4993.



When the load is suspended at the end of the crane, the vertical brace is subjected to a tensile strain, which is provided for by its attachment to the iron shoes at the ends. To resist the torsional strain in the saddle, caused by the diagonal draught of the main chains, an arm is projected some distance from the saddle, and carries a roller, Fig. 4996, that presses upon the inside of the framing, and relieves the main track. The sheaves and general tackle are of the ordinary construction.

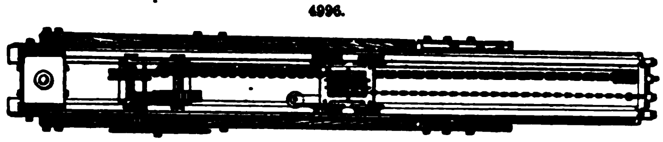
Figs. 4997, 4998, are of a steam travelling crane used in the construction of the Grand Trunk Railway of Canada. The steam engine and boiler, with its driving gear, is supported upon a platform at one extremity of the transverse carriage, being fixed thereto, and travelling with it, in a longitudinal direction.

The advantages sought by this crane are, that the steam-power travels with the traversing carriage, and does not require longitudinal shafts or bearings, which is the case when a fixed engine is employed; the lubrication and friction of the longitudinal shafting being also saved. A pair of small direct-acting horizontal high-pressure steam-engines A A are secured to the two main timbers B B of the traversing carriage. The boiler C is constructed for burning wood; the tubes are made of solid copper, without seam or joint, so that the acid from the wood cannot corrode them. The engine and boiler with the driving gear are protected from the weather by a cabin D D constructed of light framework and covered with a corrugated iron roof. The power of the engine is transmitted by a spur-pinion O upon the middle of the crank-shaft, through a spur-wheel placed on the horizontal main driving shaft F, which communicates the motion for hoisting, lowering, traversing, and moving the crane longitudinally. The motions can be used independently or simultaneously. The communication of the power to the various motions is effected upon the main shaft by three sets of mitre-wheels, which are engaged or disengaged at pleasure, by means of three handles, G, H, I, that move the sliding clutch boxes as required by the attendant. Three mitre-wheels are furnished to each motion, so that whilst the engine revolves continually in one direction the reversing of any motion can be effected by the intermediate wheels.

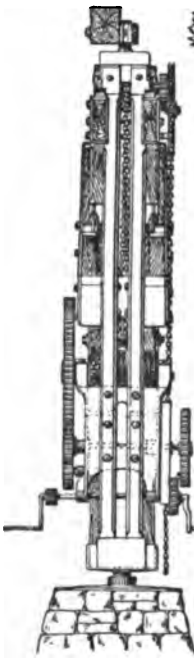
The motion for moving the carriage longitudinally is conveyed through the wheels at I, at the extremity of the driving shaft farthest from the boiler. The middle one of the three handles, H,

engages or disengages the motion K for hoisting and lowering; and the handle G next to the boiler belongs to the motion L, for traversing the crab with its weight.

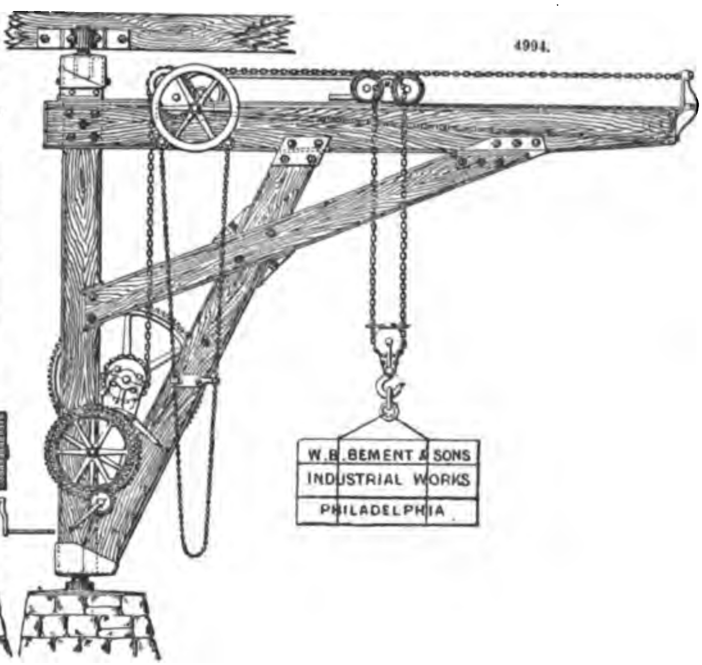
4996.



4995.



4994.



The arrangement for moving the crane longitudinally by means of spur-gearing, driving, and travelling wheels T T is similar to the plan adapted to a hand travelling crane.

The travelling wheels run upon rails M M, which are fixed at 6·4 ft. gauge, centre to centre.

The hoisting and lowering motion is transmitted to the chain-barrel K of the crab, by means of an endless chain N, which is placed in the longitudinal direction of the traversing carriage, and is driven by a pulley fixed upon the counter-shaft O parallel to the main shaft; the motion is communicated by a pair of mitre-wheels through the short intermediate shaft at right angles. This endless chain is connected to a pair of mitre-wheels fixed at the lower end of the crab-carriage, which give motion to a worm-wheel, the latter being keyed upon the chain-barrel.

The transverse motion of the crab is obtained by another chain P placed in a parallel position on the opposite side of the main timbers of the traverser carriage; this chain is attached to the four-wheeled crab, and passes over a pulley on the axis of the worm-wheel L, which is driven by the lever gear.

An additional handle R is provided for the purpose of throwing out of gear the chain N of the hoisting motion by means of the clutch-box U at the time of the traverse motion of the crab, and the chain N then runs with the crab, the pulley at U turning loose on the shaft.

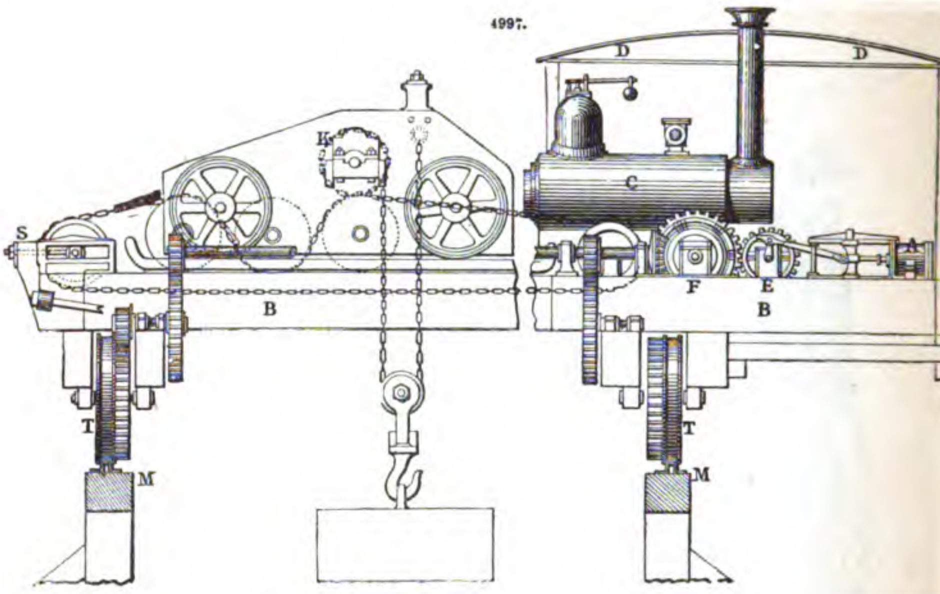
A simple apparatus for adjusting the requisite tension of these chains is provided at the farthest extremity of the two main timbers of the traversing carriage at the opposite end to the engine, consisting of a tightening pulley S S sliding in grooves and drawn back by a screw.

This crane is constructed to lift at the rate of 6 ft. a minute. The longitudinal motion works at the rate of 30 ft. and the traverse motion at the rate of 20 ft. a minute. The engines are 6 horse-power collectively.

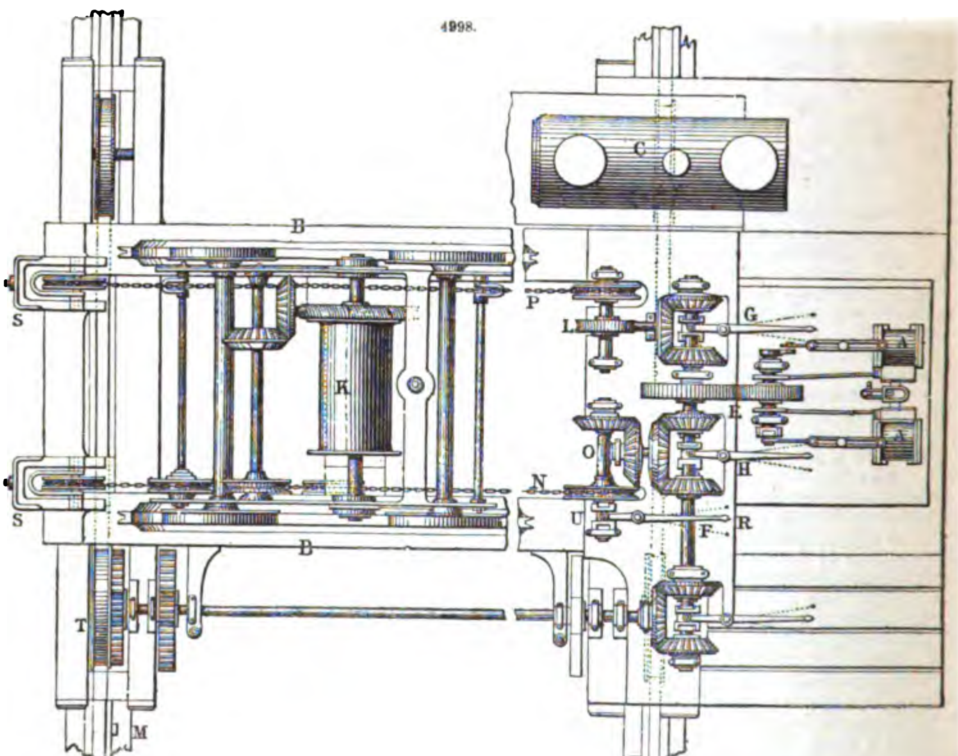
Figs. 4999 to 5001 are of a travelling crane employed at the Steam Plough Works, Leeds, for lifting locomotive engines and other heavy work, ranging from 15 tons downwards; it has a span of 40 ft., and traverses a length of 180 ft. The three different motions for longitudinal traverse, cross traverse, and hoisting, are all derived from one endless steel wire rope $\frac{5}{8}$ in. diameter, and weighing 2 lbs. a yard. This rope is driven at a speed of four miles an hour, by means of a clip-pulley, Figs. 67 to 71, p. 24, fixed at one end of the strop, which is driven by belts and gearing from the engine working the strop. The rope is entirely unsupported between the two ends of the strop, and is not strained tight, but hangs loose, with only a slight tension, because the peculiar action of the clip-pulley allows of the whole power being communicated to the rope by the grip of the pulley through half its circumference even when the tail-rope is entirely slack. The clip-pulley A, Fig. 4999, fixed

at the end of the strop, is speeded to drive the wire rope B B at the rate of four miles an hour, and lays hold of the rope with an amount of grip proportionate to the strain thrown upon the load, releasing it from its grasp when the rope has passed the centre line. The construction and fixing of the

4997.



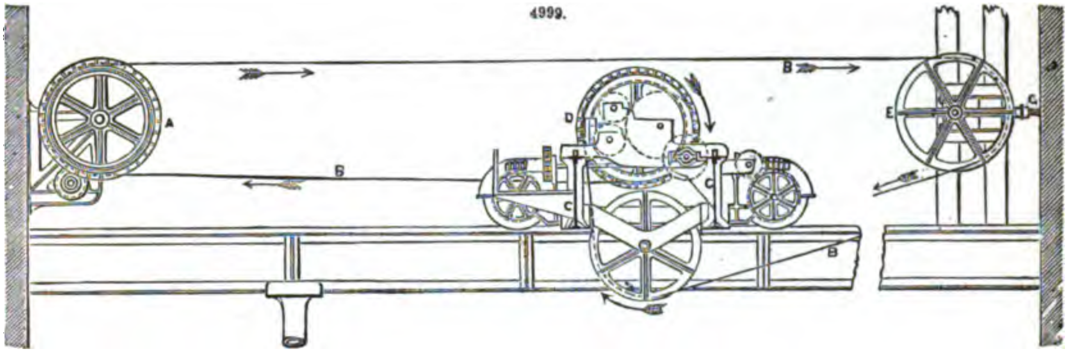
4998.



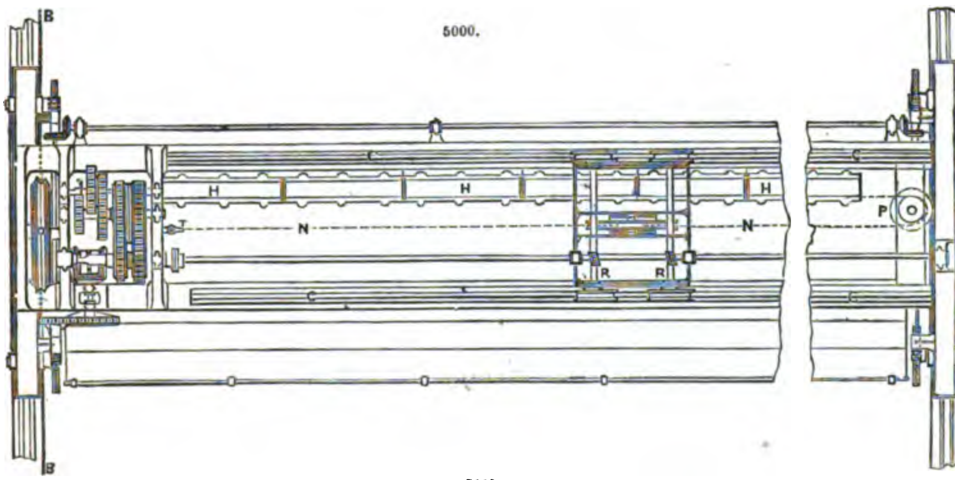
movable jaws or clip round the circumference of the clip-pulley are shown in Figs. 69, 70. At one end of the travelling platform C of the crane is fixed another clip-pulley D, Figs. 5001, 5002, of the same size and construction, round which the wire rope passes, making three-quarters of a turn

round it. The rope then passes on to the farther end of the strop, and round the grooved pulley E, at that end, Figs. 4999 to 5001; this pulley is centred in a sliding frame provided with an adjusting screw G, for tightening up the rope to any tension required. The wire rope has no slippers or

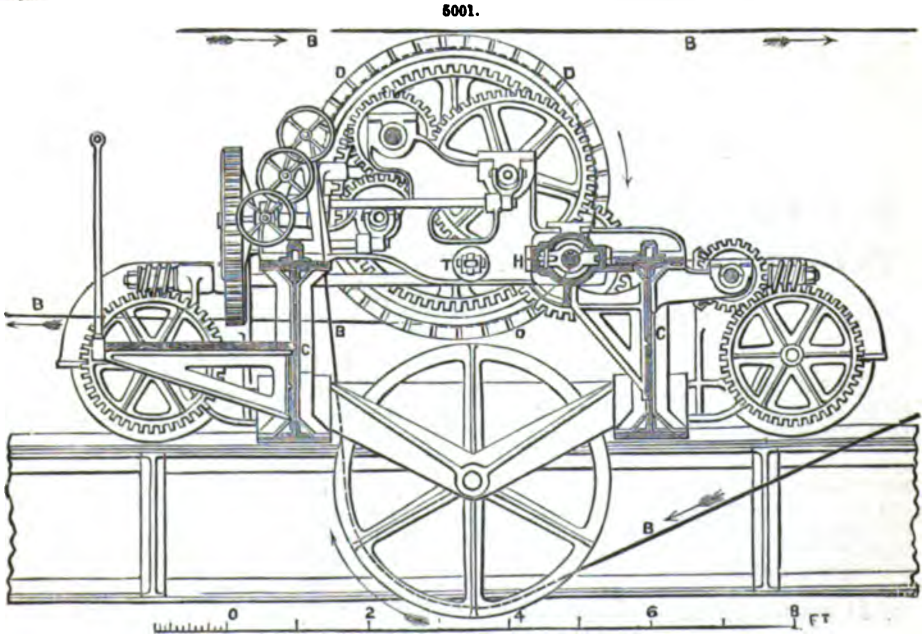
4999.



5000.

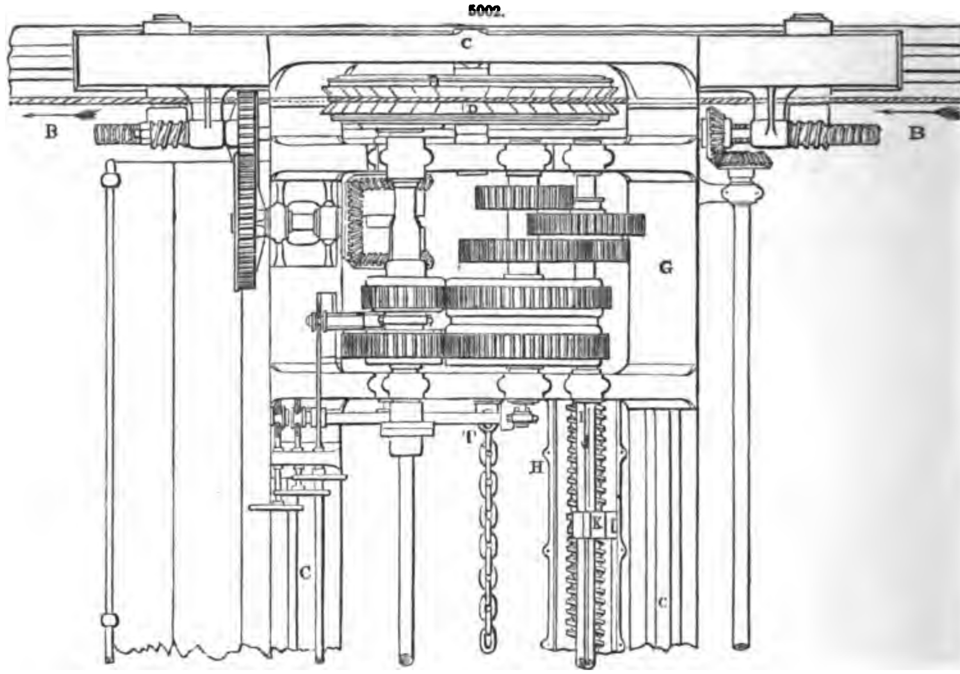


5001.



carrying pulleys to support it, and is consequently free from the friction that accompanies their use. The strop in which this crane works is 180 ft. long, and the rope hangs in a catenary curve

5002.

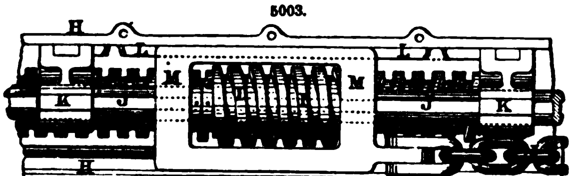


through that distance, the deflection from a straight line being from 3 in. to 2 ft., according to the degree of tightening by the end pulley E.

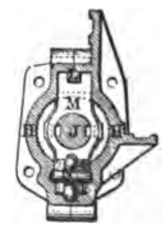
The gearing for working the longitudinal traverse and the cross traverse is of the ordinary description, the motion being communicated from the clip-pulley D on the traveller by means of friction-clutches. The longitudinal traverse has a speed of 30 ft. a minute, and the cross traverse 20 ft. a minute.

The lifting gear consists of a very long cast-iron nut or screwed barrel H H, extending nearly the whole length of the traveller, Fig. 5000, and inside the barrel works a short screw I, Fig. 5003, sliding on two feathers upon the long shaft J J, which is driven by a friction-clutch from the clip-pulley D on the traveller, so that by the revolution of the shaft the screw is traversed along within the barrel. The long driving shaft J is supported at intermediate points of its length by the two sliding brass steps K K, Figs. 5003, 5005, sliding along freely within the barrel H, and kept apart from each other at the distance of half the length of the barrel by the long rod L; thus the shaft J

5003.



5004.

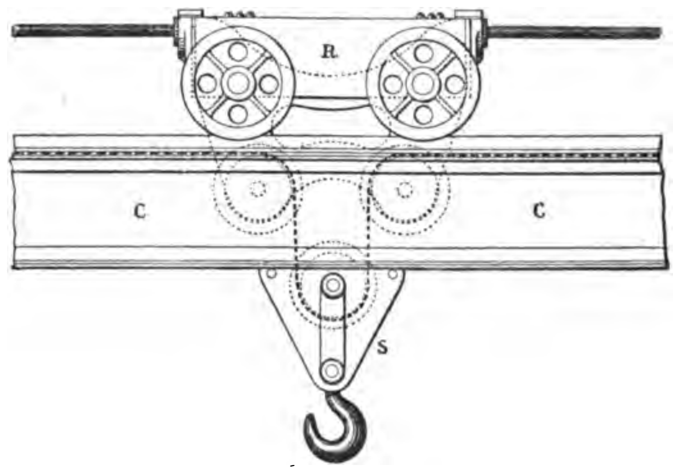


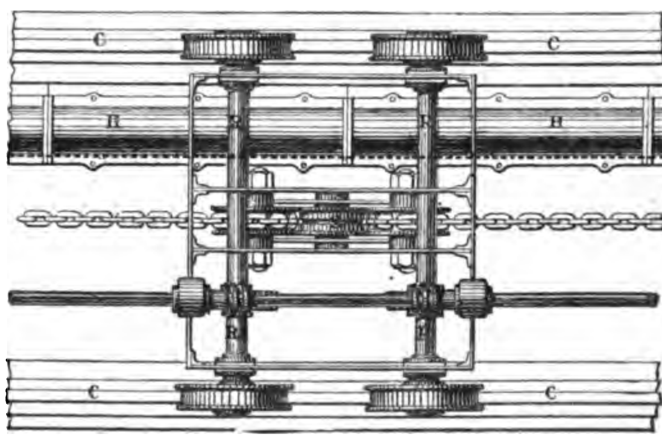
5005.

is never left unsupported for more than half of its length. The screwed barrel H is cast in two halves longitudinally, and bolted together as in Fig. 5004; and the pitch of the screw thread is 1¾ in., the diameter being 6½ in. One end of the hoisting chain being attached to the screw frame M, Fig. 5003, the chain N passes along through the inside of the barrel H round a pulley P, Fig. 5000, at the farther end of the traveller, then over a pulley on the cross traversing carriage R, Figs. 5006, 5007, down to the snatch-block S, and up again over a second pulley on the carriage R, and the end is attached to the nearer extremity of the traveller at T, Fig. 5000. There is no reason, however, why an ordinary crab might not be used, worked by a shaft extending from end to end of the traveller; and that plan has been adopted in certain cases; but for heavy weight it is still considered that the long screwed barrel is preferable. The crane has two speeds for the lifting gear, one being at the rate of 6 ft. a minute, and the other at the rate of 3 ft. a minute; and at the latter speed the crane is calculated to lift 15 tons.

It is most desirable that all machinery of this kind should be kept constantly running so as to be available for immediate use at any moment when required without any delay for starting it to work; but inasmuch as the total time during which the crane is actually in use does not amount to more than one hour out of ten, it is of special importance that the power employed to drive the rope when the crane is not in use should be reduced to as small an amount as possible. If a quick running rope is employed, the absorption of power for keeping it in constant motion forms a large proportion of the total power required when lifting a load, and this is a loss which is always going on throughout the day; but when a slow speed of rope is employed this constant loss is greatly reduced. The pull required to put the wire rope in motion when the crane is standing idle is 128 lbs.; when lifting a load of 10 tons at the usual speed of 3 ft. a minute, the additional pull upon the rope due to the load is 191 lbs., making the total pull 319 lbs., and the horse-power required with the wire rope is constantly 3·4 horse-power, when standing idle these amounts being very much less than in the case of a quick-moving cord crane.

5006.





5007.

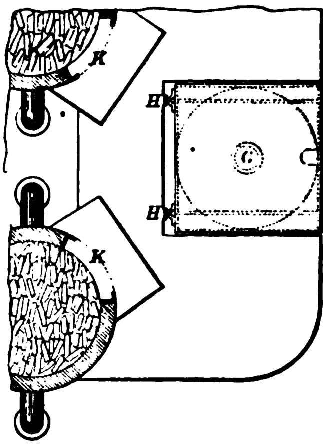
Figs. 5008 to 5010 relate to foundry hoists introduced by John Fernie, of Derby.

Fig. 5008 is a general plan of the hoist, as arranged with a pair of cupolas working together; Fig. 5009, vertical section of the hoist and cupola, showing the hoist raised in its highest position. Fig. 5010 shows the construction of the hoist in detail. A is a steam-cylinder 20 in. diameter, fitted loosely with a piston which has a range of 3 ft. Steam is supplied to the cylinder by the wrought-iron pipe B of 1¼ in. bore, by means of a three-way cock, which admits the steam or allows it to escape as required. The exhaust-pipe has a cock at its far end by which the time of the descent of the hoist is regulated. The cylinder is sunk in the ground, with its top level with the surface, and is surrounded with non-conducting material. C C C is a 4-in. cast-iron pipe running from the bottom of the cylinder to the bottom of the hoist, a length of about 40 yds. D is the cylinder of the hoist 12 ft. 9 in. long, bored out from end to end to 8 in. diameter, and sunk in a well, the top being about 12 in. below the level of the ground. The piston or ram C has a cup leather screwed on at the bottom to serve as packing. F is the piston-rod, formed for the sake of lightness of a wrought-iron pipe 3½ in. diameter and about ¼ in. thick, carrying at the top the light cast-iron platform G, 4 ft. square, on which the barrow or wagon, loaded with materials, is run. The platform is steadied in its ascent by the guides H; I I are india-rubber washers to break the shock of stoppage at top and bottom.

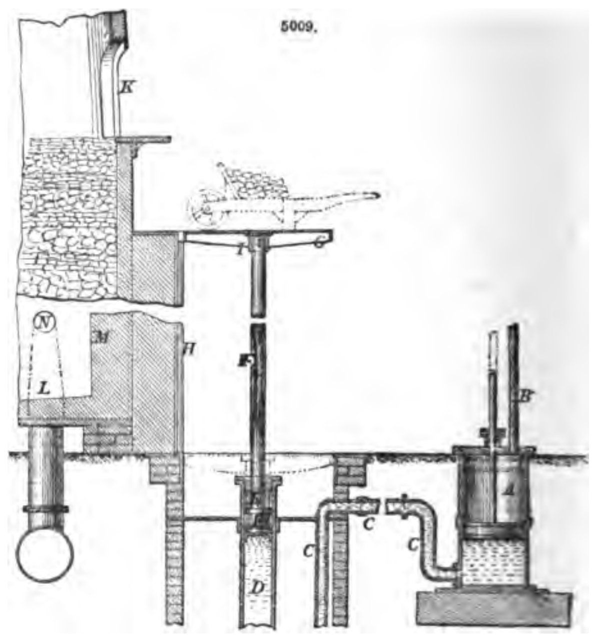
In working the hoist, the pipes C C C are first filled with water, till the piston of the steam-cylinder A rises up to the top of the cylinder, the water being supplied through a wrought-iron pipe ¾ in. bore from the force-pump of the engine that drives the fan. As there is always a little leakage at the cup leather of the piston E of the hoist, the capacity of the steam-cylinder A is made larger than that of the hoist-cylinder D to allow for this loss being nearly in the ratio of 2 to 1. The barrow or wagon being run on the platform, the steam is admitted on the top of the piston and the hoist begins to ascend. For the first stroke or two condensation takes place pretty

freely, and the hoist rises slowly; but the cylinder and water gradually get warm, and after a few strokes no perceptible condensation takes place. The hoist ascends the 10 ft. in 20 seconds when

5008.



5009.

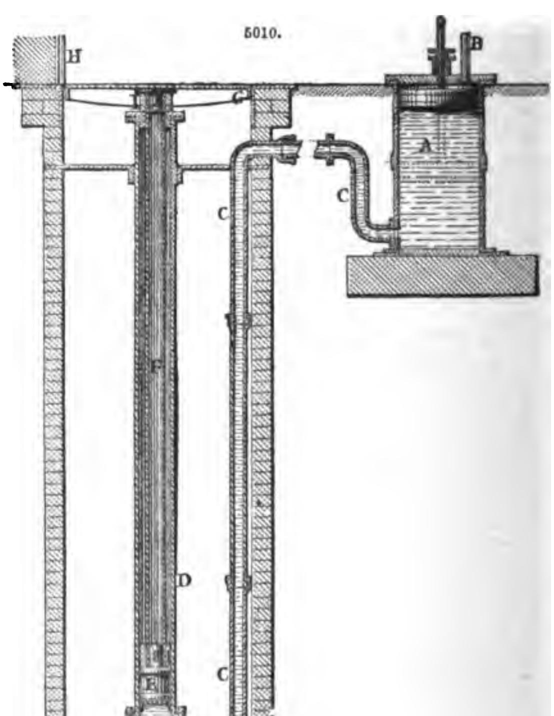


loaded with 9 cwt. and descends in 30 seconds, the steam being turned on and off by the engineman; the men at the hoist make signals when they want the hoist to ascend or descend, and it begins to move immediately, with scarcely any perceptible loss of time.

The hoist was originally calculated to lift 10 cwt. at a time, the pressure of the steam being 40 lbs. the sq. in., and the diameter of the ram E 8 in., making the total pressure upon it 18 cwt., but it can take up conveniently only 9 cwt., and the weight of the platform, piston-rod, and ram being about 3 cwt., there remain 6 cwt. or about 30 per cent., of which just so much is lost in friction as leaves an effective pressure sufficient to set the hoist in motion at the required speed.

Fernie made several experiments to ascertain the consumption of coal required to work the hoist, and has found that 1 cwt. a day, in addition to the usual quantity, 6 cwt., used by the engine, is sufficient to lift two 5-ton charges of iron a day.

5010.

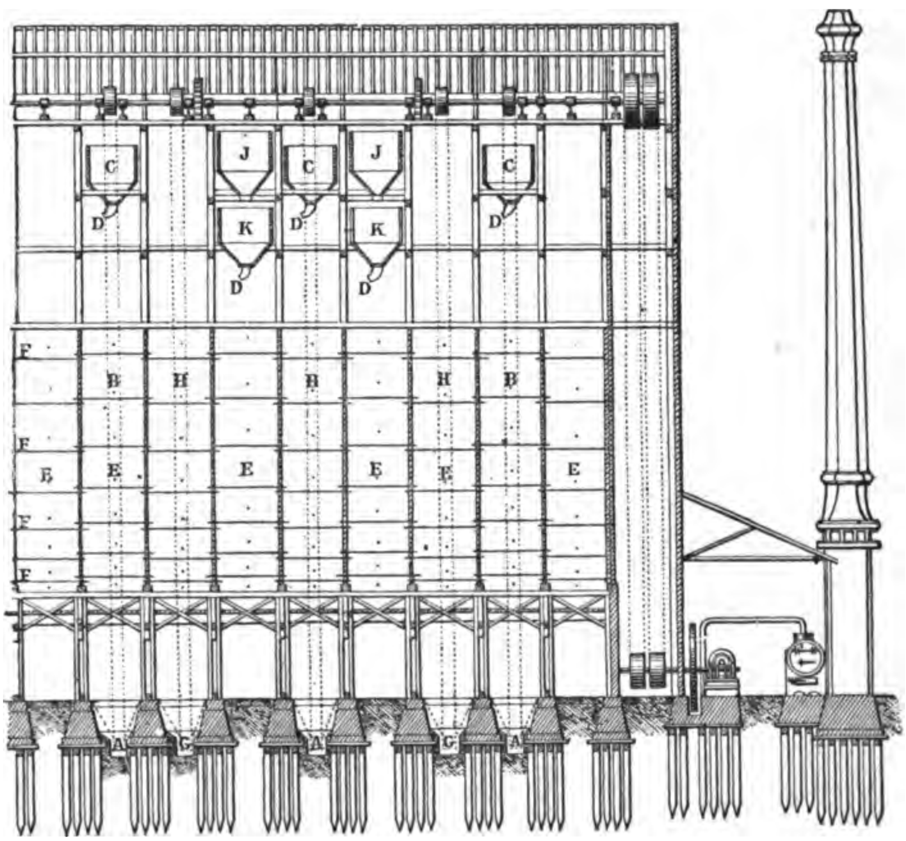


Elevators.—In the United States the name of Grain Elevators is given to certain establishments in which the transshipment of grain is carried on, and in which it is often stored for whole months together. It is weighed when taken in, and again when sent out. The removal of the grain from one spot to another, necessitated by these operations, is almost wholly effected by means of machinery in a very small space, and in a very little time. There are establishments capable of storing from one to one and a half million bushels of corn at once, and these may take in from five to eight thousand bushels an hour, and send out twice that quantity. If it be borne in mind that distinctions of sender, receiver, and owner have to

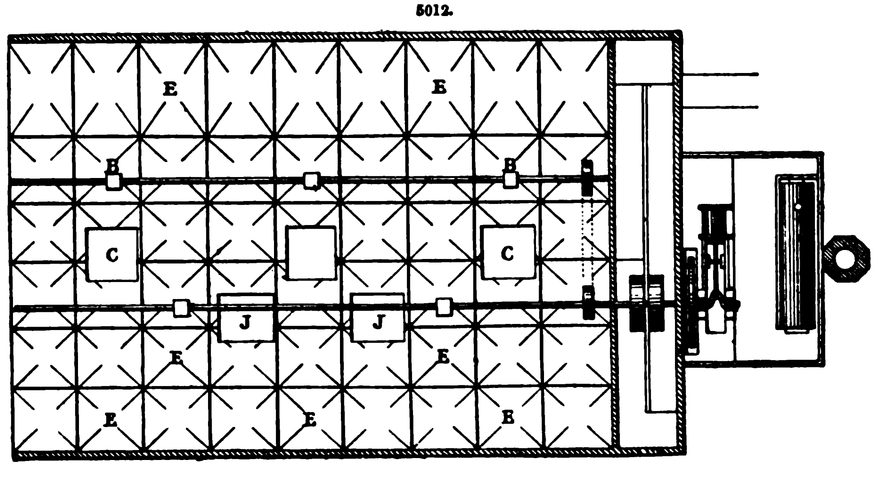
be kept, it will be seen that the problem solved by the grain elevators is a very complicated one.

At Chicago the grain is brought in wagons and put on board vessels which cross the great Northern lakes. At Buffalo these vessels discharge their cargoes either into the barges of the Erie Canal, or into the trucks of the New York Central or the Erie Railroad. And finally at New York the grain is transferred from the barges or the trucks into large ships for exportation. At Chicago and at Buffalo the establishments are fixed. They are buildings approachable by vessels upon one or two sides, and into which one or two tramways run on a level with the adjoining ground. Bucket elevators raise the grain, moving in an inclined plane and passing through the

5011.

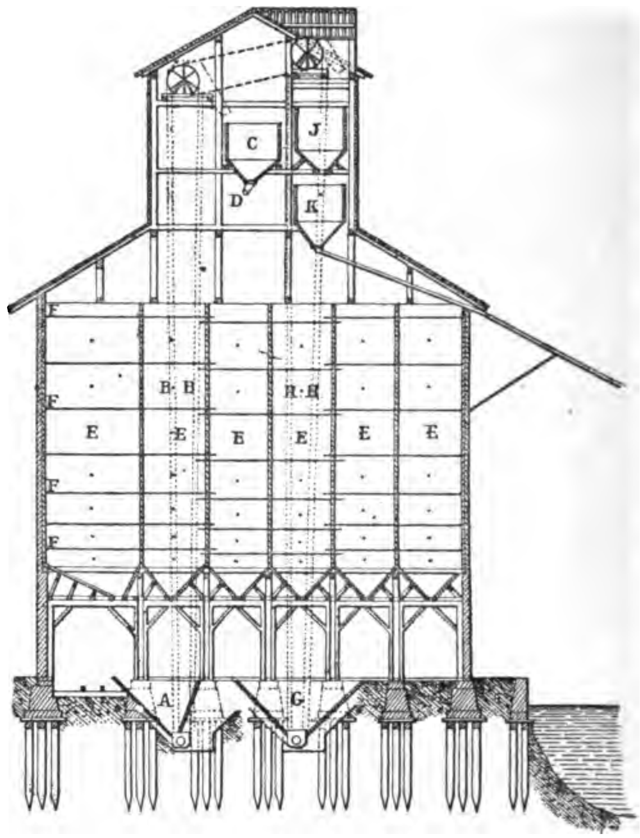


5012.



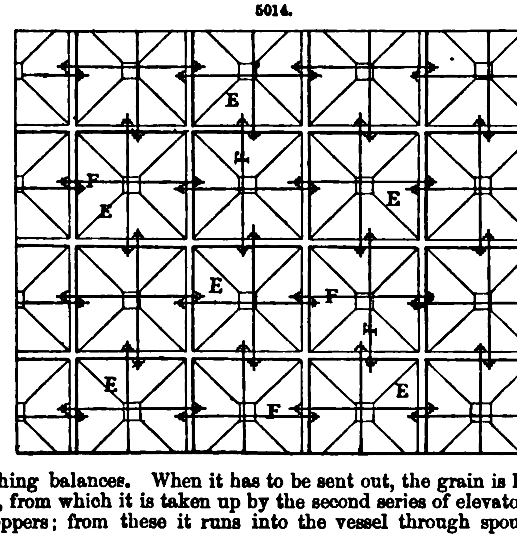
wall if they are intended to work on the outside into a vessel; in a vertical plane if they are intended to dip into pits into which the grain is shot from the trucks. In order to weight it, it is stopped at the beginning of its downward motion in a weighing hopper resting upon a balance. To clean it, it is let fall from the top of a cylinder 15 or 20 ft. in length, up which a strong current of air is driven by a fan. The grain is stored in compartments or bins 10 ft. square and 50 to 65 ft. deep. The bottoms of these bins, which are placed together like the squares of a draught-board, are 12 or 15 ft. above the ground. These bottoms are of the form of a mill-hopper, like those of the various receiving, weighing, and discharging hoppers, in order that the grain may run out of its own accord through an orifice of limited section. A small annexe to the principal building contains the engine and boiler. The motion is transmitted to one or two horizontal shafts in the upper part of the building, often at a height of 100 ft. These shafts drive the elevators.

5013.



Such are the general arrangements. We will add a few details concerning the elevators of Chicago, Buffalo, and New York. Figs. 5011 to 5014 represent the plan, longitudinal and cross sections, and the detailed plan of bins for one of these establishments. A A are receiving wells; B B, receiving elevators; C C, receiving hoppers; D D, spouts; E E, bins; F F, iron bin-rods; G G, discharging wells, H H, shipping elevators; J J, shipping garners; K K, weighing hoppers. The building is 210 ft. long by 75 broad, and extends to the river's bank. A tramway enters on the opposite side. There are 108 bins, capable of containing altogether nearly half a million bushels. These bins rest upon piles at a distance of 15 ft. from the ground, and reach up to the level of the eaves. Above the roof and along the middle of the building is a wooden structure 36 ft. in breadth, in which the hoppers and the horizontal shafts are placed. The double rows of elevators, in this case all vertical, ascend to the top. Before reaching the store-bins the grain is raised by the receiving elevators up to the receiving hoppers, from which it descends through the medium of weighing balances. When it has to be sent out, the grain is let down into a second row of drawing pits, from which it is taken up by the second series of elevators into other hoppers called shipping hoppers; from these it runs into the vessel through spouts passing through the wall.

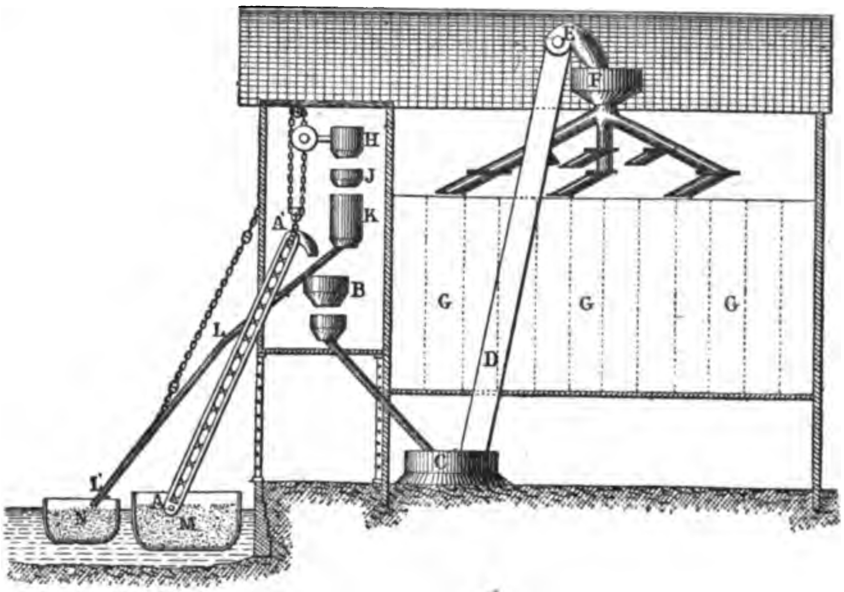
5014.



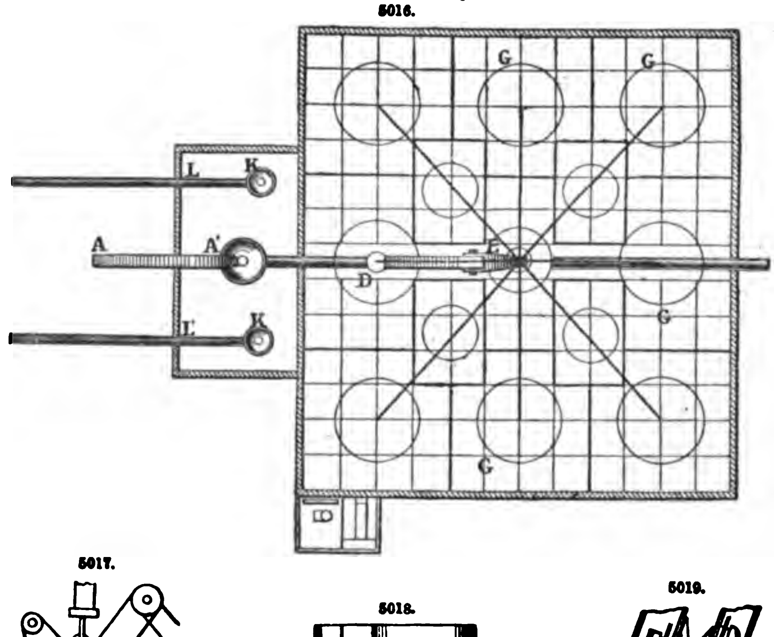
At another of these establishments at Chicago there are two tramways running along the front of the building, and two others entering it. The total capacity of the bins is a million and a half bushels. It takes about an hour to load a vessel of 300 tons. The steam-engine is of 200 horse-power.

At Buffalo, which seems to be above all others the place for grain elevators, there are from fifteen to twenty of these establishments. Figs. 5015 to 5019 represent some of the details of one of these belonging to the Niagara Company. A A′ is the elevator for raising grain from the lake boats;

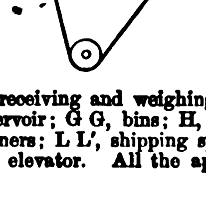
5015.



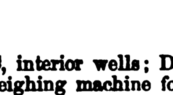
5016.



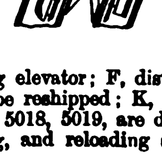
5017.



5018.



5019.



B, receiving and weighing hoppers; C, interior wells; D E, receiving elevator; F, distributing reservoir; G G, bins; H, bolter; J, weighing machine for grain to be reshipped; K, shipping garners; L L′, shipping spouts; M, lake boat; N, canal boat. Figs. 5018, 5019, are details of the elevator. All the appliances for unloading, weighing, cleansing, and reloading are here

collected into a tower which is erected on the brink of the river. The main building, which is devoted to storage purposes, is 130 ft. square, the height being equal to the other dimensions. This arrangement requires a horizontal transport of the grain. The appliance by which this is effected is an endless belt consisting of a broad band of stout canvas sewn to two bands of india-rubber, which rest upon two rows of friction-rollers. The grain lodges in a longitudinal depression of the canvas. The unloading elevator is 75 ft. long. The frame which gives it the necessary rigidity is suspended from the woodwork of the roof by its upper end, and sinks with the load in the vessel. This displacement of the upper drum causing the distance between it and the driving shaft to vary, there is some difficulty in transmitting the motion. This difficulty has been overcome in the following manner;—The belt connecting the two does not go directly from one to the other; the under portion of the belt, Fig. 5017, passes under a fixed pulley, and the upper portion under a movable friction-roller, which rests its whole weight upon it, being held up by a block moving between vertical slides. The speed of the elevator is about 450 ft. a minute. The sheet-iron funnel in which the grain is received before passing up into the weighing hopper is closed at the bottom by a horizontal slide moving upon small friction-rollers, so that it may slide easily notwithstanding the load upon it. The weighing hopper forms another funnel simply closed by a hinged flap or hatch moved by a handle. Usually a hundred bushels are weighed at once.

Before reaching the bins, the grain falls upon the top of a kind of tower, from which eight tubes radiate, inclined at 30°. To the lower end of these tubes are fixed others, inclined to the same degree, and capable of being turned about the first as about a vertical axis. By means of these pipes all the bins may be readily filled.

The height of the bins varies from 52 to 72 ft. Their capacity is about 4800 bushels, and collectively they are capable of containing 800,000 bushels. The partitions which separate them are formed of planks placed one upon another, the breadth being 10 in. at the bottom and 15 in. at the top.

The belt, or, as it is called, the conveyer, by which the horizontal transport is effected, moves with a velocity of 200 ft. a minute. In order to discharge its load upon any point in its course, the horizontal direction of the upper portion of the band is broken by means of two pulleys, between which is placed the hopper of a discharge shoot. These three pieces one above the other are mounted upon the same frame or bed, which, supported upon two axles, runs upon a little tramway in the space which separates vertically the two portions of the band, on a level with the floor of the basement story, upon a floor laid over with cement. Another travelling frame carries a system of pipes by means of which the grain from any one of the bins may be brought upon the conveyer. Thus one horizontal conveyer is sufficient for five rows of bins. The vertical elevator which takes the grain up again is 140 ft. in height.

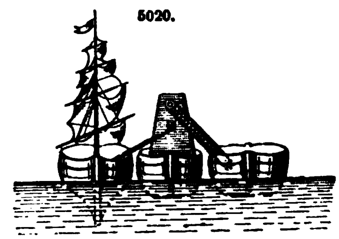
When the grain has to be loaded into trucks it is not necessary to raise it as in the case of loading into vessels. The trucks are merely run under spouts in connection with the conveyer. They are then weighed by running them on to a weighing machine.

The establishment is capable of raising 7000 bushels an hour from a vessel, and at the same time discharge into barges 14,000 bushels, without reckoning that which may be loaded into railway trucks or into special vehicles.

It may be mentioned that the walls of most American grain elevators are composed of planks of wood laid one upon another, in successive courses, decreasing in width towards the roof. In cases where the bins have been constructed of iron, the riveted joints have been torn asunder by the wedge-like action of the falling grain.

The elevators of New York are much more simple, because the cleansing of the grain has been effected at Buffalo, and the barges may retain their cargoes for some time. Occupying, consequently, less space, and transferring the cargoes from one boat to another, the establishment itself may be afloat, as in Fig. 5020. In such cases it is taken to the most convenient part of the bay, or of the two rivers which flow by New York, Brooklyn, and Jersey City. The floating elevator is naturally placed between the barge and the ship. A bucket elevator raises from one what is to be transferred by means of spouts to the other.

5020.



The following description of the method, proposed by Colonel Henry Flad, for raising the arches of the bridge of St. Louis is a subject that may be properly introduced here, while considering the nature of various appliances for raising heavy weights.

The great span of the arches of the bridge of St. Louis (524 ft.), the importance of the navigation, which could only be interrupted in one of the three bays at once, and the nature of the bed of the river, the floods of which would inevitably carry away the supports of scaffolding erected in the space between the piers and the abutments, combined to render the work of getting up the segments of the arches one of extreme difficulty. The method employed at the bridges of Fribourg, Argenteuil, and other places, was not applicable here, ingenious as the method was. Nor were the appliances adopted by R. Stephenson for the erection of the tubular bridge over the Menai Straits more suitable. The following is the method that was to be employed as described at the time by Flad;—

"Upon the two piers and abutments two towers will be constructed of timber, and upon these towers will be laid strong wire cables, which will enable a traveller to run from one end to the other, carrying either workmen or portions of tubes. Suppose now the arch made up of six symmetrical portions, the sketch is easily made, A B, B C, C D; D′ C′, C′ B′, B′ A′. The portion A B will be placed upon the abutment, and the end B supported by a cable passing over the tower and fixed behind. The two portions abutting on the next pier will be placed in the same manner, and, by means of the similar cable, will balance each other. Then the portion B C will be lowered,

resting its lower end on B, the other end C being supported by a cable passing over the top of a king-post B o and fixed at A. The same will be done for B′ C′. When this is done, the middle portions C D, C′ D′, will be let down, which will have to be fitted at C and C′ with the former. The fitting together of these will require the ends C and C′ of the segments already placed to be moved tentatively up or down; but how is this delicate problem to be practically solved? The gable b, instead of resting at the top of the tower upon an oscillating sector or upon a roller, will rest upon the rounded head of the ram of an hydraulic press. In this way the levels may be varied by insensible degrees. And to render the equilibrium independent of the variations of temperature, the cylinder of the press will be made to communicate with a small vertical tube, the piston of which will support a plate suitably loaded."

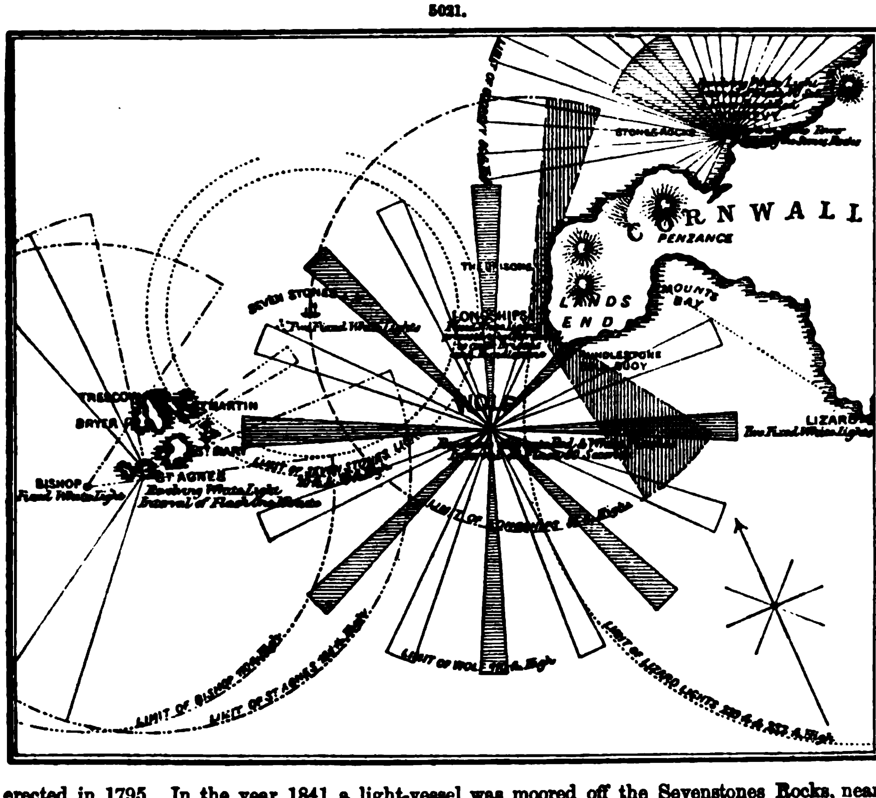
LIGHTS, BUOYS, AND BEACONS.

The rocks, sands, and other obstructions along a sea-coast render it necessary that certain constructions should be used to warn mariners, both by night and by day, of their dangerous proximity. Such constructions are called lights, buoys, or beacons, the most important being lights or lighthouses, which are buildings generally carried up in the form of a tower, either along the sea-coast as landmarks, or upon dangerous rocks. Lights of various descriptions are introduced upon the top of the tower at night, and a balcony usually runs round the lantern on the outside. Lighthouses of a similar kind are frequently erected at the extremity of one of the arms forming the entrance to a harbour, for the purpose of guiding vessels in and out during the night; these are usually called *harbour lights*. The Eddystone Lighthouse, built by Smeaton, is very celebrated; it presents a fine specimen of scientific construction, and has been taken as a model from the time of its construction up to the present.

The details of a series of arrangements for lighting the rocky coast off the Land's End, England, were incidentally described in a paper upon the Wolf Rock Lighthouse, read by Jas. N. Douglass before the Inst. C. E., in 1870, from which we have taken the following;—

In consequence of applications from the foreign and coasting trades navigating the English and St. George's Channels for lights and beacons to mark the dangers of the coast near the Land's End, a lighthouse on the Longships Rock, Fig. 5021, and beacons on the Wolf and Rundlestone were

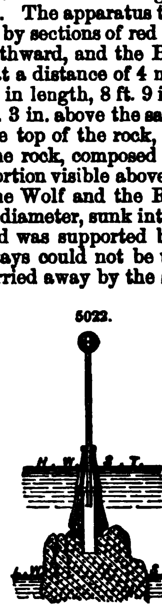
5021.



erected in 1795. In the year 1841 a light-vessel was moored off the Sevenstones Rocks, nearly midway between the Land's End and Scilly, in 40 fathoms of water. These were all works of considerable difficulty, for the group of rocks included under the name of Longships, lie about 1 mile westward of the Land's End, and 7¾ miles N.E. from the Wolf, and are composed partly of killas or clay-slate and partly of granite; the division running through the eastern part of the lighthouse rock, in a north-easterly and south-westerly direction. The Longships Lighthouse is a granite structure, from which is exhibited a catoptric fixed light, and it has rendered good service to the mariner; but owing to the terrific seas to which it is exposed, the lantern, with its centre at an eleva-

tion of 79 ft. above high water of spring tides, was so much under water during stormy weather, that the character of the light could not be determined with certainty. It was not considered safe to raise the tower to a sufficient height to render the lantern free from the heaviest seas; and it was therefore necessary to erect in its stead a granite column 110 ft. high, surmounted by a First Order dioptric light, and which was commenced in 1869. The apparatus to be installed therein will admit of an arrangement being carried out for marking by sections of red light the dangers of the Rundlestone Rock and its surrounding shoals to the southward, and the Brissons Rocks to the northward. The Rundlestone, Fig. 5021, lies S. by E. ¾ E., at a distance of 4 miles from the Longships, and is ¾ of a mile from the shore. It is about 17 ft. 9 in. in length, 8 ft. 9 in. in breadth at the level of low water of spring tides, and the highest part is 8 ft. 3 in. above the same level; but the only available space for the base of a beacon is a portion of the top of the rock, 4 ft. 4 in. long by 4 ft. broad, at a level of 7 ft. above low-water spring tides. The rock, composed of hard grey granite, forms part of a dangerous group of shoals, and is the only portion visible above low water of spring tides. The beacons, referred to as having been erected on the Wolf and the Rundlestone Rocks in 1795, were merely bare poles of wrought iron, about 4 in. in diameter, sunk into the rock, and run in with lead. That on the Wolf was about 20 ft. in height, and was supported by six wrought-iron stays. The beacon on the Rundlestone was not so high, as stays could not be used, owing to the small size of the rock, Fig. 5023. Both of these were soon carried away by the sea. In addition to the beacon on the Rundlestone, the position of the rock was indicated by day by two marks of rubble masonry, erected on the land, at a distance of 1 mile. These are 220½ ft. apart, and when brought in line they lead over the centre of the rock. The second beacon placed on the Rundlestone, Fig. 5022, was designed by Jas. Walker, and was erected during the years 1841-3. The work was one of great difficulty and danger to those employed, owing to the small dimensions of the rock, and the difficulty of landing, which could only be accomplished at spring tides; and then the sea was seldom smooth enough to admit of a footing on the rock, as a strong tide-runs to the westward during the whole of the time that the summit is uncovered. This beacon, after having been several times damaged, and twice swept away, was eventually replaced by a bell buoy, Fig. 5024, designed by J. N. Douglass. The bell, weighing 3 cwt., is fixed on a wrought-iron stand attached to the deck, and is rung by four long pendulum-clappers, which are Y-shaped, and thus have two points of suspension, rendering unnecessary the use of the ordinary guides. The length of swing is limited by india-rubber buffers, attached to the iron plate surrounding the superstructure, and on which the name of the station is painted. The buoy is constructed with a central water-tight compartment, large enough to float it, in the event of a vessel fouling and driving in the outer plating. A second water-tight compartment is formed at the bottom, which is used for water-ballast in cases where the buoy may be required to be placed in shallow water. The weight of the buoy complete is 65 cwt. That at the Rundlestone is moored with 32 fathoms of long-link mooring chain and a 24-cwt. sinker; 16 fathoms of the chain at the lower end is of 1¼-in. iron, and the remainder, or upper part, of 1-in. It is moored in 16 fathoms of water, S.W. ¼ W. from the rock, at a distance of 1½ cable, on a rocky bottom and in a strong tideway. It is found to ride well, and to ring efficiently in all states of the weather.

5022.



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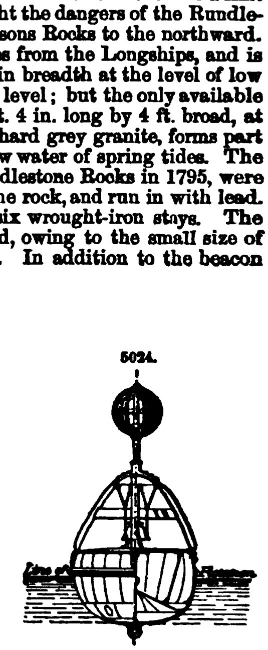


The Wolf Rock, shown in plan and section, Figs. 5025 to 5027, is situated in latitude 49° 56′ 41″ N. and longitude 5° 48′ 30″ W. From it the Lizard lighthouses bear E.S.E. 23 miles; St. Agnes Lighthouse, Scilly, W. by N. ½ N. 20¾ miles; Longships Lighthouse, N.E. ½ N. 7¾ miles. The rock is composed of a hard, dark, felspathic porphyry; its highest part 17 ft. above low water of spring tides, which rise 19 ft. The surface is rugged, rendering a landing upon it at all times difficult. The depth of the water close to the rock is about 20 fathoms on all sides, except the S.E., where a shoal extends for a considerable distance, having only 4½ fathoms to 5 fathoms on it at low water at a distance of a cable's length from the Wolf. At a distance of 1 mile from the rock the depth of water on this reef is about 14 fathoms, but in every other direction it is not less than 34 fathoms.

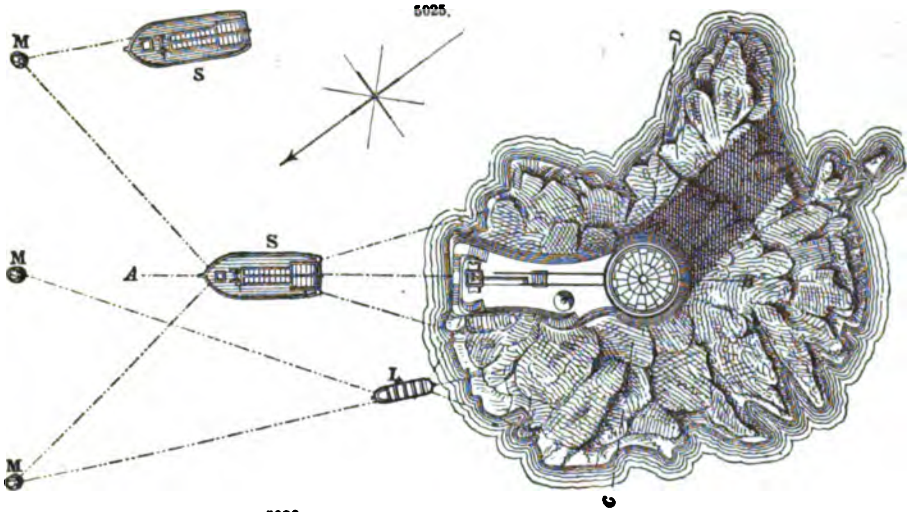
Between the periods of high water and the following low water, the tidal stream runs south-easterly, southerly, and south-westerly; whereas, from low water to the succeeding high water it sets north-westerly, northerly, and north-easterly. This peculiarity is supposed to extend to a radius of 4 leagues from the rock. Situated as the Wolf Rock is, in deep water, and exposed to the full force of the Atlantic Ocean, a terrific sea falls upon it, as may easily be surmised.

The iron beacon, Fig. 5028, was erected on the Wolf during the years 1836 to 1840.

The difficulties of the undertaking were so great, that during the five years the workmen were only able to work 30½ working days of ten hours each. The mast, which was of selected English oak, 12 in. in diameter, was carried away as early as November of the last-mentioned year. Immediate steps were taken for replacing it by one of wrought iron, 7½ in. in diameter, Fig. 5029; but no opportunity occurred for effecting its erection during the following summer. It was, however, carried out in August, 1842. This mast was bent during the succeeding winter about 3 ft. from the perpendicular, the bend being in the direction of the heaviest seas, namely, from the westward to the eastward. During a storm in October, 1844, the mast was again broken off, at

about 4 ft. above the top of the cone. In July of the following year a second iron mast was fixed, Fig. 5030. In this case the mast was increased to 9 in. in diameter, and the globe was reduced to

5025.



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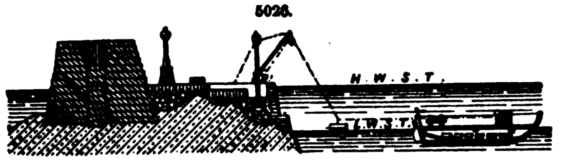
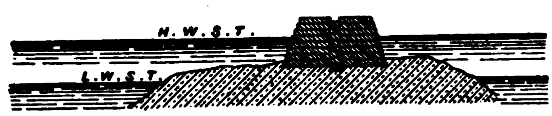


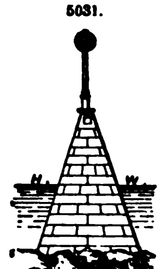


5027.

5030. 5029. 5028.

4 ft. in diameter. This mast stood until the early part of 1848, when it was carried away. In August, 1850, another wrought-iron mast, Figs. 5031, 5032, was fixed. It was 9 in. in diameter at the lower part, and had a globe only 3 ft. in diameter. This mast withstood the force of the sea until it was taken down during the progress of the construction of the present lighthouse. The ironwork of the beacon, after an exposure of thirty years to the corrosive action of sea-water, is in a good state of preservation, having been protected by a coat of red-lead paint, renewed annually. Some of the internal cement rubble filling was removed for the purpose of affording space for the stowage of the workmen's tools during the erection of the lighthouse, when the threads of the screw-stays that were imbedded in the cement were found to be as perfect as when first made.

5031.



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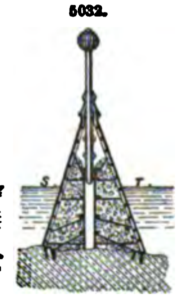


The craft employed at the Wolf Lighthouse were a steam-tug of 60 horse-power, and five barges, each of 40 tons burden, for the conveyance of the stone and other material from the yard to the work. In addition to these, a schooner of 100 tons register was built, and specially fitted for service as a barrack for the workmen when afloat. Special moorings were laid down for these vessels near the workyard at Penzance, 17 miles distant, and a timber jetty was erected for loading and unloading them.

The Wolf Rock Lighthouse was designed by Jas. Walker, and the erection entrusted first to Jas. N. Douglass, and afterwards to W. Douglass. The exact height of the tower is 116 ft. 4⅜ in., its diameter at the base 41 ft. 8 in., and near the top, at the springing of the curve of the cavetto under the lantern gallery, the diameter is 17 ft. For a height of 39 ft. 4½ in. from the base the work is solid, with the exception of a space forming a tank for fresh water. At the level of the entrance door the walls are 7 ft. 9½ in. thick, whence they gradually decrease throughout the whole height of the shaft to 2 ft. 3 in. at the thinnest part near the top. The shaft of the tower is a concave elliptic frustum, the generating curve of which has a major axis of 236 ft., and a minor axis of 40 ft. It contains 44,506 cub. ft. of granite, weighing about 3296⅜ tons; and its centre of gravity is 36 ft. 2¼ in. above the base. In consideration of the exposed position of the work, it was determined to dovetail each face-stone vertically and horizontally. This method of dovetailing,

Figs. 5033 to 5035, consists in having a raised dovetail band, 3 in. in height, on the top bed, and one end joint of each stone. A corresponding dovetailed recess is cut in the bottom bed and end-joint of the adjoining stones, with just sufficient clearance for the raised band to enter it freely in setting. From experiments made upon blocks of granite put together in this manner with Portland cement, it is found that the work is so homogeneous as to be as nearly as possible equal in strength to solid granite. This system of dovetailing also affords great protection to both horizontal and vertical joints against the wash of the sea when the work is first set. In addition to the security afforded by the dovetailing, each stone of the first and second courses of masonry is secured to the rock by two yellow metal bolts, 2 in. in diameter, each bolt being sunk 12 in. into the rock, and fox-wedged at each end; a portion of the hole at the top and the bottom being made conical for the purpose. From the third to the twentieth courses inclusive, each face-stone is secured to the course below by two yellow metal bolts, Figs. 5037, 5038, 2 in. in diameter, and each internal stone by two bolts of galvanized puddled steel, also 2 in. in diameter. Each bolt in these courses is sunk 9 in. into the course below. All the holes for the bolts were bored on the platform in the work-yard, and so accurately was this executed, that no instance occurred where the lower part of a hole was found to be out of position for properly inserting and wedging up the bolt at the rock. Figs. 5037 to 5043 are plans of the courses, and Fig. 5044 plan of gallery, lantern, and illuminating apparatus at level of service stage. The masonry, to the level of high-water spring tides, was set in fresh Medina Roman cement. All the cement used in the work was mixed with an equal portion of clean, sharp granitic sand, obtained from the stamps refuse of a tin mine. This sand is of excellent quality for such work, every grain in it being hard, angular, and rough. Salt water was used for mixing all the cement required for the landing platform and the solid portion of the tower; above this only fresh water was used.

In spite of the precautions taken for the security of the stones in the lower portion of the building, thirty-four stones of the fifth course, which course it was found impossible to complete at the end of the season of 1865, were carried away during a heavy storm which raged on the 24th and the 25th of November of that year.

The general internal arrangements and fittings are shown on the section of the tower, Fig. 5036. The step-ladders for ascending from floor to floor, and the partitions between the rooms and staircase, are of cast iron, and the use of wood for the fittings has been limited as much as possible, as a precaution in case of fire. The doors, windows, and storm-shutters are constructed of gun-metal. The windows of the watch or service room, immediately under the lantern, are specially arranged for admitting air to the lantern, and for regulating the ventilation in all ordinary weather. The supply of air is admitted by a valve at the upper part of the window, so as to pass above the head of the light-keeper on duty, and upwards through an iron grating surrounding the lantern floor. The lantern is one of the cylindrical helically-framed type, designed by J. N. Douglass, and adopted by the Trinity House.

With the view of giving the Wolf Light a perfectly distinctive character, a revolving dioptric light of the First Order, showing alternate flashes of red and white at half-minute intervals, was resolved upon. This arrangement involved the consideration of the important question, which does not appear to have been previously determined with accuracy, of disposing in each beam the relative proportion of light to allow for the loss in the red beams by passing through a ruby glass medium, and produce at all distances at which the light can be seen, with variable states of the atmosphere, flashes of nearly the same strength. The investigation of the subject was entered into by Professor Tyndall, and from practical tests it was determined that the quantity of light to be appropriated to the red beam should be to that of the white in the ratio of 5275 to 2250, or as 21 to 9 nearly.

The apparatus has sixteen panels of refractors and lower prisms, and eight panels of upper prisms, to the circle. Eight panels of refractors and lower prisms of 18° each are appropriated to eight beams of white light; and eight panels of refractors and lower prisms of 27° each, together with the eight panels of the upper prisms of 45° each, to eight beams of red light. The colour is produced by ruby glass placed in front of the panels, and revolving with the apparatus. The illuminating power of each beam sent from the apparatus is estimated at 2250 French units.

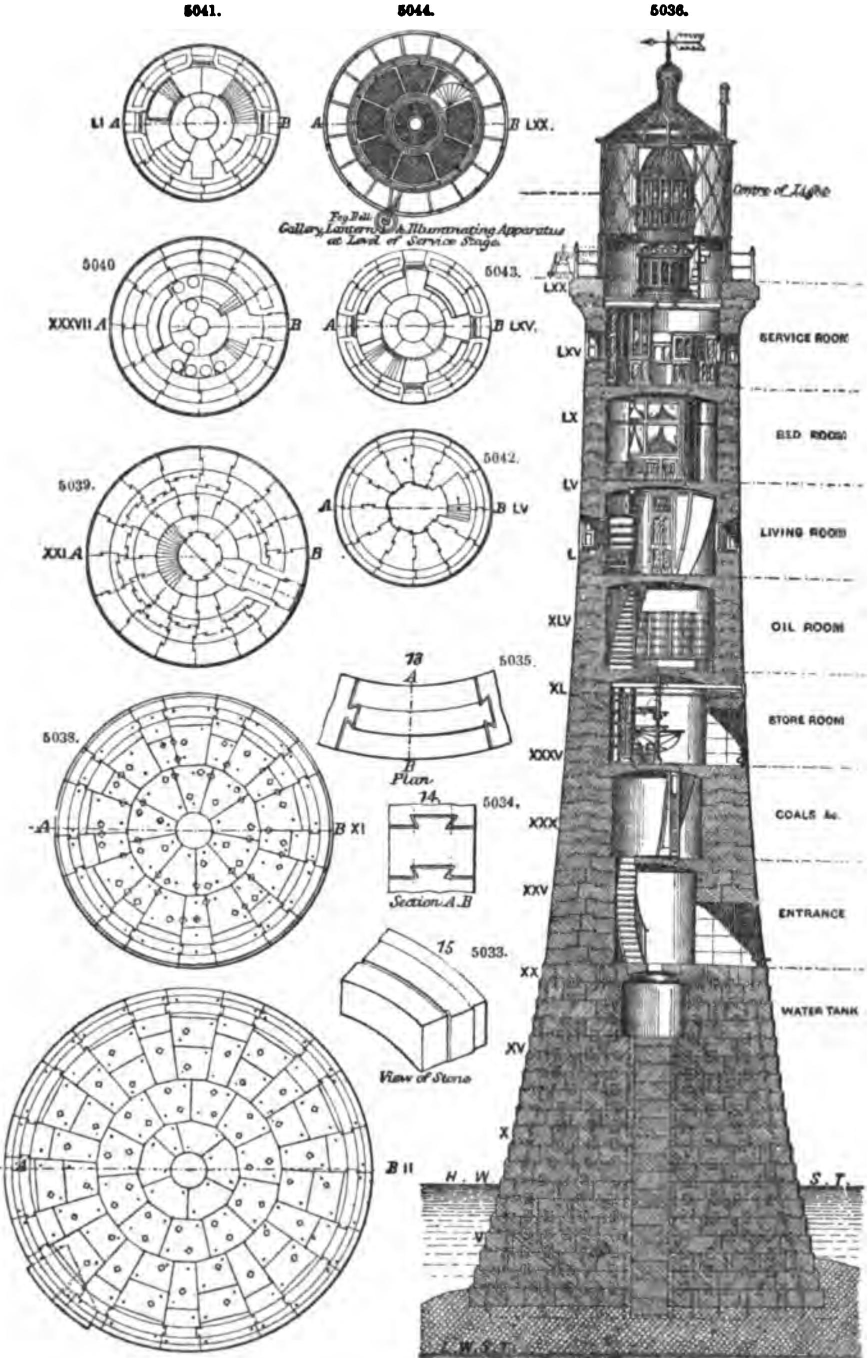
A 5-cwt. fog-bell is fixed on the lantern gallery, Fig. 5036. It is struck by two hammers worked by machinery fixed in the pedestal of the illuminating apparatus, but independent of that for rotating the latter. For the purpose of giving the signal a distinctive character for the station, the machinery is arranged for striking the bell three blows in quick succession at intervals of fifteen seconds.

In consideration of the great difficulty that would be experienced in landing upon the Wolf, which can only be effected on the north-east side, and even there the surface is rugged and without any vertical face for a boat to approach, it was determined to construct a landing platform, Fig. 5025. As the material for this platform could only be landed from boats, small granite ashlar, set in cement, similar to brickwork in old English bond, was adopted. The stones, with the exception of the larger ashlar in the steps and coping, and some rubble-filling obtained from the foundation pit for the tower, are each 24 in. by 12 in., by 6 in. in thickness, rough pick-dressed, and are laid in fresh Medina Roman cement. Frequent tides, which did not ebb low enough to admit of working at the foundation pit for the tower, were worked at this platform; and so rapidly did this portion of the work progress that the platform was nearly completed before the foundation pit was prepared for setting the first stone of the tower. The platform greatly facilitated the erection of the light-house, and will prove of permanent value, from the convenience it affords for landing and embarking at times when it would be impossible to effect this without it. The landing platform contains 14,564 cub. ft. of masonry, making together with the tower a total of 59,070 cub. ft., or about 4375½ tons.

The first survey for the purpose of determining the exact position of the proposed tower was made on the 1st July, 1861. Douglass landed upon the rock, and made the best use he could of the short time which the state of the tide allowed; but the sea getting up meanwhile put a stop to his work; and as a boat could not, from the increased swell, approach the rock with safety, he was hauled on

board through the surf by a line fastened round his waist. This mode of embarking was frequently resorted to afterwards for getting the workmen off the rock, when caught by a sudden change of weather and increase of surf.

5041. **5044.** **5036.**



Plans of Courses. *Section on Line A.B. on Plans of Courses*

5037.

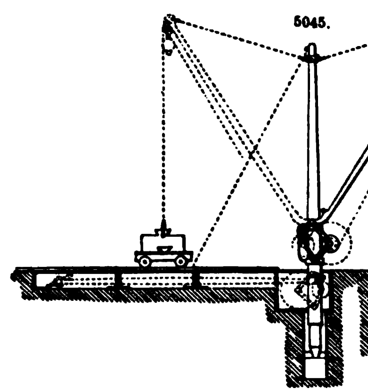
On the 17th March, 1862, the working party got upon the rock, and began to cut out the foundation pit. The insecurity of the foothold, and the constant breaking of surf over it, rendered

great precaution necessary for the safety of the workmen. Heavy iron stanchions were sunk into the rock around the site for the foundation, and each man worked with a safety-rope lying near him, one end of which was attached to the nearest stanchion. An experienced man was always stationed on the summit to look out for the sea, who would give warning of such waves as were likely to sweep the rock, when the men would hold on, head to the sea, while it washed over them; picks, hammers, and jumpers, some exceeding 20 lbs. in weight, were frequently found to have been washed away, when the waves had passed and were followed by a lull.

On the 29th September the last tide of the season was worked. Only twenty-two landings had been effected, and eighty-three hours of work obtained on the rock for the season, although not a single opportunity had been lost when it was possible to work even half an hour. The season was altogether a very unfavourable one for such an undertaking. During these eighty-three hours considerable progress was made in blasting and cutting out the foundation pit for the tower, and in the erection of the landing platform.

In 1863 the first landing was effected on the 20th February, and the last on the 24th October. During the season thirty-nine landings were effected, and the work on the rock was proceeded with during 206¼ hours. At its close the cutting of the foundation pit and the erection of the landing platform were about half executed, and the dressing of the sixth course of masonry in the workyard was completed.

The first landing for 1864 was effected on the 9th April, and the last on the 5th November. During this year forty-two landings were effected, and 267 hours' work obtained on the rock. On the 6th August the first stone of the tower was set. At the close of the season thirty-seven stones of the first entire course, or second course of the tower, were set; the landing platform was nearly completed, and the dressing of the tenth course was finished in the workyard. The iron derrick landing crane, Figs. 5045, 5046, was erected on the end of the landing platform. It has a solid wrought-iron mast, 10 in. in diameter, fixed in a cast-iron well, into which the machinery, when not in use, is lowered by a rack and pinion, and is there secured by strong wrought-iron hinged covers. The wrought-iron derrick, when not in use, is lowered into the long protecting chamber, and is secured therein with strong iron covers.



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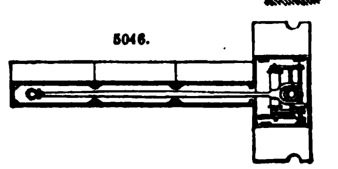

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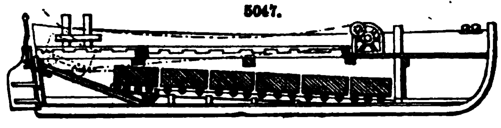

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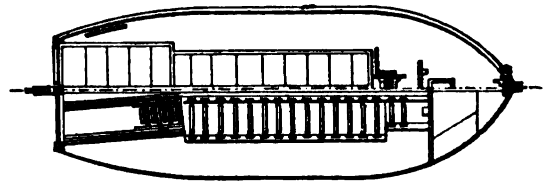


5048.

In Figs. 5047, 5048, the upper and lower deck plans and a longitudinal section of one of the stone barges are given. The lower hold of these barges is fitted with elm rollers, running on iron gudgeons, on which the stones were stowed, in the order in which they were wanted for the work. Each stone, as required to be landed, was rolled on to one of the trucks at the stern of the barge, and drawn up to the level of the deck by a chain led from the winch on the deck; the chain from the landing crane was then shackled to the lewis fixed in the stone; the single block of a strong rope veering tackle was also attached to the lewis as shown; one end of this tackle was secured to one of the windlass bitts, and the other end to a brake-barrel on the winch. As the chain of the landing crane drew the stone from the truck over the roller at the stern of the barge, with the heave of the vessel, the veering tackle was eased away by the brake, and the tackle kept just sufficiently taut to prevent the stone being driven by the sea against the rock. Blocks of stone have frequently been landed without damage in this manner, with a rise and fall of wave of 12 ft.

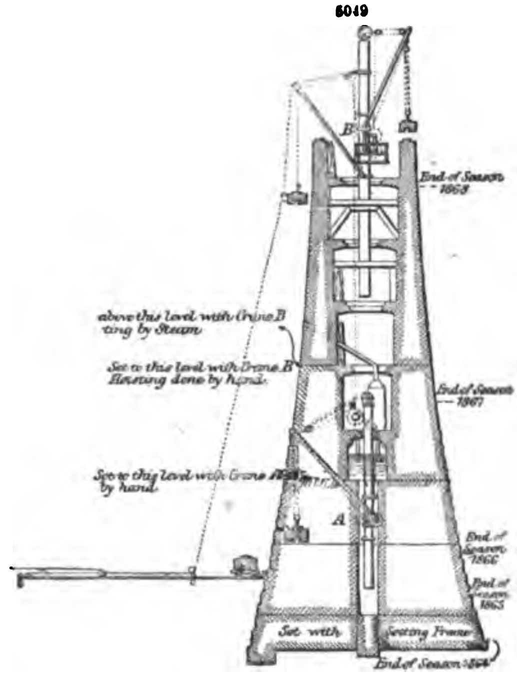
The relative positions of the mooring buoys, barges, and landing boat, when engaged at the rock, are shown Fig. 5025, where S S indicate stone barges, L landing barge, and M M spherical mooring buoys. Each barge, when at the landing crane, was moored, stem and stern, with 10-in. coir-hawsers; and the stern hawsers even of this size, which being shorter than those at each bow had not so much to give and take, were frequently parted. The barrack schooner, for the accommodation of the resident engineer, his assistants and working party, was moored E.N.E. from the rock, at a distance of ¾ mile, and remained there as

long as there was an opportunity of doing any work. When this was no longer possible, and there was no immediate prospect of better weather, the moorings were slipped, and the vessel was taken to Penzance, there to await another opportunity.

Fig. 5049 shows the arrangement of the lifting and setting gear, and the progress of the work during the first five years.

Figs. 5050 to 5053 are a perspective view, with plan and sections of the landing boat used for the work. This boat is built diagonally, of two ½-in. thicknesses of elm plank, without timbers or floors, and is provided with a landing-deck and mast forward. The deck and gunwale forward are covered with rough rope-matting, for the purpose of affording a good foothold in jumping from or into the boat. Each workman was provided with a cork life-belt, which he was compelled to wear while landing on or embarking from the rock; and it was frequently necessary, for the safety of the men, that they should wear these belts during the whole of the time that they were engaged upon the rock.

5049



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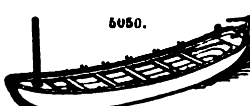

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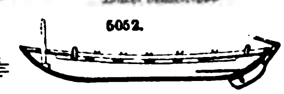

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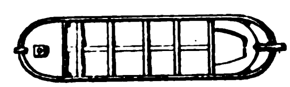

5051

The moorings laid near the rock for the vessels were as follows;—Those for the sailing barrack-vessel were laid about ¾ mile E.N.E. from the rock, in a depth of 36 fathoms, on a bottom composed of coarse sand and shells. The moorings consisted of a 30-cwt. mushroom anchor, 90 fathoms of 1¼-in. chain, with a swivel and riveted shackle at every 15 fathoms, and an iron spherical mooring buoy, 5½ ft. in diameter. As it was necessary that the vessel should be securely attached to the mooring, and yet be free to slip from it readily under canvas, in such a manner as to avoid drifting on the rock, the following method was adopted;—A piece of chain, of the same size as the mooring chain, and about 3 fathoms in length, was shackled to the mooring chain at 3 fathoms from the buoy. To the upper end of this chain was shackled about the same length of ¾-in. chain, and the end was carefully stopped to a mooring ring at the crown of the buoy. In mooring the vessel, the end of the small chain was detached from the buoy, and was passed over an iron roller at the bow, and twice round the windlass. The end of the mooring chain, when hove in, was stopped to a strong eye-bolt in the deck abaft the windlass; the end of the small chain was then passed back over the windlass and roller at the bow, and secured in the same manner as before to the buoy, which was hoisted on to the bow of the vessel and there lashed. When it was necessary to slip from the moorings, the buoy was first thrown overboard, and then the chain was slipped from the windlass, the whole operation being easily performed in one minute.

Each of the three moorings close to the rock, for securing the stone barges, was laid in about 25 fathoms water; each mooring consisted of two 24-cwt. cast-iron sinkers, 30 fathoms of 1¼-in. ground chain, and 15 fathoms of 1-in. upper chain, to which was shackled a 5½-ft. iron spherical mooring buoy, with a strong mooring eye at the crown, to which the craft was secured. These moorings, laid on a rough, rocky bottom, in a strong tideway, and with a continuous swell, were subject to great wear, especially the portion on the ground. They were usually laid between the latter part of February and the early part of March of each season, and were taken up between the latter part of October and the early part of November. It was generally found that the iron in the chain was reduced in diameter during the above period nearly as follows, namely, from the buoy to 20 fathoms, $\frac{1}{16}$ of an inch; this portion of the chain, where the links were not in contact, being coated with short seaweed and crustacea. From 20 fathoms to 30 fathoms the chain was quite bright, and nearly uniformly reduced in diameter ¼ in. From 30 fathoms to the sinkers, 45 fathoms, the chain was rather bright, and reduced about ⅛ of an inch. No shackle, even with its pin well riveted in when hot, could be trusted in the part of the chain where the greatest wear occurred; the incessant hammering on the rock soon loosened the pin, and rendered it unsafe. All the mooring chains used were long linked, and without studs. Each mooring was lifted and carefully examined once or twice during the season as opportunity offered; and when taken up at the end of each season, they were thoroughly overhauled, and the worn parts cut out and replaced by new.

The work steadily progressed year by year, until on the 19th of July, 1869, the last stone was laid.

Maplin Sand Lighthouse.—The mouth of the river Thames is intersected by numerous sandbanks at its junction with the ocean, and upon one of these banks is erected the Maplin Lighthouse. The channel to the south of the Maplin Sands was formerly marked by a floating light. In light-vessels a lantern encircles and slides upon a short mast, and is raised or lowered by a crab and chain; these vessels are rendered more conspicuous during the day by being painted of a bright red colour, and a globe about 6 ft. in diameter formed of thin wooden ribs connected together by belts of the same material, is placed at the top of the mast.

The establishment in these vessels consists of six or seven men, who are relieved every two months. The light-vessels afford a good light by night, and are floating beacons by day; but are liable to drift from their moorings, or to suffer damage from vessels running foul of them, as they are generally in the fairway of the channel. In the event of their breaking from their moorings, serious calamities are liable to occur to shipping; and this having occurred with the light-vessel at the Maplin, means were taken to erect a small permanent iron lighthouse, and from J. B. Redman's paper on the subject in Trans. Inst. C. E., 1848, we learn that Mitchell's system of screw-piles was used for the foundations.

One pile was placed at each point of an octagon, with one in the centre, and they were screwed down into the sand in the following manner;—A raft, about 30 ft. square, had been previously prepared, with a longitudinal opening from one side to the centre for the admission of the pile; this was towed over the spot where a pile was to be screwed down, and was held in its proper position by means of warps, the pile being pitched upright, and projecting through the opening left for that purpose; a capstan-head was then keyed on to the pile at the proper level, the bars were introduced, and by manual labour the piles were screwed down, the capstan-head being shifted up as the piles descended, the average work being one pile a day.

The labour required for screwing the piles down varied much, but for the most part the sand appeared to be clean and firm for about the first 8 ft., and then became looser for about 3 ft., the rest being generally uniform.

The piles were screwed down 21 ft. below low water, Fig. 5054, their tops being 5 ft. above

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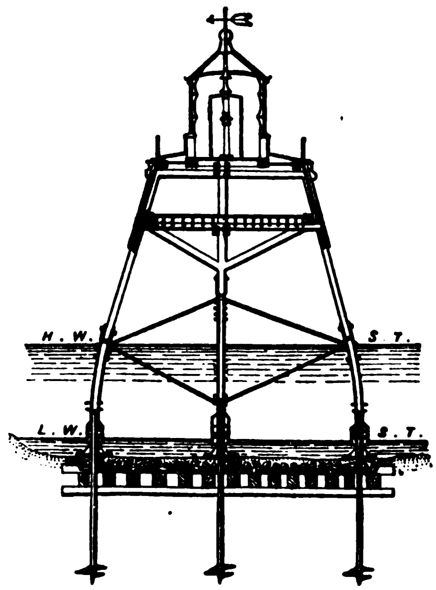

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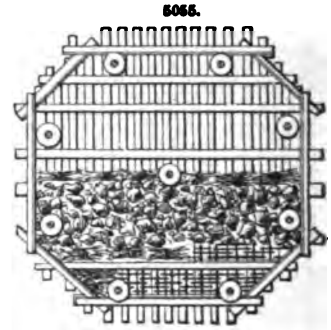

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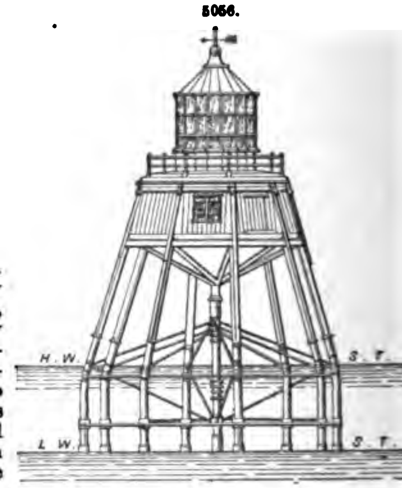

that level, and from 4 ft. to 4 ft. 4 in. above the sand. In a few tides the sand was found to be considerably lower at the S.E., being 6 ft. below the pile-heads, whilst at the northward it had not undergone any change. Whether this deepening arose from the projection of the piles alone is doubtful, as the sand appeared to have decreased at the margin uniformly to the east and west. Still the obstruction of these piles to the current of the stream, though small, appeared to have had some influence; a slight hollow was worn around each pile, similar to what takes place on the sea-shore, around stones lying on the sand.

As the sand shifted so much, it was thought advisable to adopt some precautionary measures, to secure a foundation for the building. A raft, or grating, of timber was accordingly formed, Fig. 5055, towed down, and moored off the sand. The timbers of the raft were so disposed as to

admit the piles freely, and a curb extended all round, for retaining the stones intended to be placed upon it; the surface was covered with bavins, or fagots of small wood, filling the spaces level with the tops of the upper half timbers, and were fixed by means of ropes, interlaced with them and nailed to the timbers. The raft, in this state, was towed over the piles, from the tops of which leading ropes had previously been brought through the corresponding openings between the timbers; this precaution was necessary from the inequality of the sides of the octagon. One hundred and twenty tons of rough Kentish stone were then thrown upon the raft, covering it to an average depth of 15 in., causing it to sink with about two-thirds of this weight, and to ground just before low water.

From the sand having decreased so much previously, particular care was taken to obtain the levels of the raft so as to ascertain in future the amount of settlement and inequalities counteracted by adding to the higher portion an additional quantity of stone.

The ironwork supporting the superstructure, Figs. 5054, 5056, and placed immediately upon the screw-piles, consists of nine hollow cast-iron columns, or pipes, the exterior ones curved at the top to a radius of 21 ft. towards the centre, with projections to support the wrought-iron collars to which the ties are bolted. The columns, at 4 ft. from the bottom, have a stop cast in them to rest upon the piles, and are finished at the top with a socket to receive the timber columns of the superstructure; the centre column is shipped 2 ft. over the centre pile; the columns at each end are strengthened by wrought-iron hoops, put on hot, and suddenly cooled. The ties are of wrought iron, connected to the outer columns by collars with arms, embracing the ends of the ties, which are flattened out; the ties at the centre of the building are finished with projections, forming part of a circular collar, which encloses the centre column; the projecting flanges are bolted together; the braces are arranged so that there should be a tier of horizontal ties between the outer columns, about 10 in. above the pile-heads, and similar ones radiating from the centre column to the north, south, east, and west columns. Four sloping diagonal ties connect the centre column to the north-east, north-west, south-east, and south-west columns, near the level of the upper horizontal ties, and are fixed in the same way as the lower ones. These horizontal ties are attached immediately below the sockets in which the timbers rest, at which level sloping ties connect each of the exterior columns to the upper part of the centre one, which stands 7 ft. above the rest.

The columns of the timber superstructure are stepped into the iron columns, and are well braced together; the tiers of horizontal bracing form the supports for the floors and gallery. The braces are partly supported by oak cleats, screwed to the uprights, to which the half timbers are bolted, and the whole timbers abut against them, being partly let in and secured by wrought-iron gibs, keys, and cleats, and attached at the centre by wrought-iron knees and bolts.

The superstructure is further strengthened by a raking brace being placed at every external column, at the level of the lower floor, and abutting against the centre column, into which four of them are tenoned, and are secured by wrought-iron knees and bolts, the upper ends being bolted to the half timber braces of the lower floor; the lower ends of the remaining raking braces are stepped upon the others, and at the outer ends are fastened to them in a similar manner. Between each of these braces quarters are fixed, and the whole is boarded inside and out, forming the store for coals, water, &c. Both the tiers of horizontal bracing are bounded by curbs, which fit in between the main pillars, and are fastened by wrought-iron knees and through-bolts; the upper curb is level with the tops of the pillars. The joists of both floors are calked on to the horizontal bracing, those of the lower floor being tenoned into the curb.

The lantern base is supported upon a curb, in pieces 8 ft. long, the ends of which are half-lapped, bedded on, and bolted to the upper horizontal braces. The basement, or plinth, consists of sixteen sides, the angles being formed by two quarters, tenoned below into the curb, and at the top into the sill of the lantern, which is of oak, weathered and throated, and the joints dovetailed and half-lapped; the quarters are well braced, and the wrought-iron through-bolts, which hold down the lantern, pass between the quarters at each angle, and are screwed up underneath the lower curb of the basement. The plinth, or basement, is covered with two casings of boarding, an inch thick, the inner casing being placed horizontally, and the outer vertically. The joists of the lantern floor are laid, like those of the lower floor, upon the horizontal bracing and the lower curb of the lantern base; the joists of the lantern gallery rest upon the curb of the lantern plinth, and upon the upper outer curb, radiating nearly from the centre, there being one at each angle, and the whole is covered with boarding, which receives the lead flat.

The sides of the dwelling are covered both on the outside and the inside with boarding; the joints are ploughed and tongued, and each board is strongly nailed to the three tiers of quarters; the outside boarding at the bottom is rebated into an external moulded curb, which is fixed to the outside of the principal curb, and the principal posts, or columns, are rebated for a width of 2 in. at the angles, to receive the boarding; and the faces of the columns are covered with pilasters, or covering boards, rounded on the edges, and reaching about 3 ft. 6 in. below the lower curb, being terminated at the top by brackets, against which the cornice abuts. The gallery and cover boards of the cornice are covered with lead.

The window-frames are supported in a framework, the posts of which receive the quarters of the sides; the window sills are of oak, weathered, and throated in front; the sashes are single, and, like the shutters, slide up and down inside the outer boarding.

The door is on the north-west side, and the quarters of the side are tenoned into the posts, the jamb linings being nailed to these posts; the sill is of oak, throated and weathered, and the head is finished like the jambs. The two leaves of the folding doors are framed and battened with deal 2 in. thick, and when shut they are flush and fair with the outside of the dwelling.

The interior of the dwelling is arranged and partitioned off, so that the sleeping berths are kept distinct from the living room, by having small state rooms and doors in front. The store has bins for tow, provisions, and so on; in it are kept the oil cisterns, and the stairs up to the lantern are enclosed by partitions. The communication with the lower store, in which coals are kept, is by a

trap close to the entrance doorway; the water-closet and water-tanks are likewise placed in this lower store.

Outside of the entrance door is a landing, or platform, from which the ladder descends to the level of the top of the north-west iron column, where it is supported by a cast-iron bracket; on the surface of this ladder, the second length slides upon rollers travelling on wrought-iron plates. This portion of the ladder reaches to near low water, and is raised by means of a rope and barrel, worked by a ratchet-wheel and lever, the rope having balance-weights at the other end, which slide up and down against the face of the pillar. There is also a brake for lowering it; by this contrivance the building can be reached at any time of the tide, as the lower end of the ladder, when let down, reaches sufficiently near to the surface of the water at low tide to enable persons to land on it.

The principal dimensions and scantlings are;—

Ironwork.

Screws		4 ft. diameter
Piles	26 ft. long,	5 in. „
Cast-iron columns (external) .. .. .. and $1\frac{1}{8}$ in. thick.	18 „	11 in. „
Lower wrought-iron ties		$2\frac{1}{4}$ in. „
Upper ditto		2 in. „
Wrought-iron screw-bolts to couplings of ties		$\frac{3}{4}$ in. „

Timber Work.

	in.		in.
External columns, 30 ft. long, 12 in. square at the bottom, and $10\frac{1}{2}$ in. at top.			
Half timber horizontal braces	12	×	$4\frac{1}{2}$
Upper whole ditto	10	×	10
Lower ditto	11	×	10
Raking braces	10	×	10

Joiners' Work.

Lantern curb	12	×	9
Oak sill to ditto	12	×	6
Oak window sills	12	×	9
Oak door sill	12	×	9
Door posts	6	×	5
Jamb linings to door	$2\frac{3}{4}$ thick		
Outside boarding to sides of dwelling	2 „		
Inside ditto	$1\frac{1}{4}$ „		
Pilaster boards	2 „		
Boarding to lower store	2 „		
Ditto to lead flat	2 „		

For the superstructure, the cast-iron bases were first shipped over the pile-heads, dropped upon the stonework of the raft, and solidly bedded; on the tops of these bases were placed concentric rings, forming washers, fitting loosely over the piles, and of various thicknesses, so as to render the bases of one uniform level at the top.

The columns were then all put up, and the wrought-iron work was fitted; a stage was erected on the upper horizontal braces to facilitate the erection of the timber framing, upon which the lantern was placed; the light was a French dioptric light of the Second Order; its centre, 45 ft. above the mean level of the sea, and at this elevation it may be seen from the deck of a ship for a distance of nearly ten miles, Fig. 5056.

A bell is fitted on the gallery, to be sounded at regular intervals in dark and foggy nights, by means of clockwork within the lantern base.

A space of 2 in. was left between the tops of the bases and the lower ends of the columns; so that, in the event of the piles sinking with the weight of the building, after settling 2 in., the structure would rest upon the bases, and through them on the large bearing surface of the raft, amounting to about 1700 sq. ft., being fifteen times the area of the nine screws, the bearing of which is 113 superficial feet, being 12·56 ft. to each pile.

As the water ebbs at times below the tops of the bases, the piles were exposed for a length of 2 in., giving the bases a somewhat weak and unsightly appearance. To obviate this, nine covering irons were cast, the exterior ones being 2 ft. in length, and the centre one 3 ft.; they were each formed of two semicircular pieces, fitting together with lapped joints, and screwed with counter-sunk screws, having each a projecting flange inside to support them on the bases. The upper part of the bases and the lower ends of the columns were thus enclosed, and at low water these covering irons had the appearance of bases to the columns, and they fitted loosely, so that, in the event of any settlement, they would offer no obstruction to the columns. A mark was made on the outside of each column, 12 in. above these bases, to ascertain if any subsidence did occur. This, of course, could only be observed to the extent of 2 in., when, as before described, the structure would bear upon the raft.

The total weight of the structure is about 72 tons, being a weight of 8 tons a pile, or $12\frac{3}{4}$ cwt. a superficial foot of bearing surface of the screws at the ends of the piles.

The usefulness of a lighthouse entirely depends upon the accurate construction and effective working of the light-giving appliances, and no engineer has given this subject greater attention than D. M. Henderson, to whose paper upon Lighthouse Appliances and Lanterns, in the Trans. Inst. C. E., 1869, we are indebted for the succeeding particulars.

There are, writes Henderson, six orders of catadioptric apparatus in general use, the first three designated sea-lights, and the second three harbour-lights, but modifications in size have been made for particular cases.

The largest size of apparatus is that known as the First Order, having an internal diameter of 1·84 mètre = 72·442 in., and a height of glass of 2·704 mètres = 106·447 in. In the old section there were thirteen upper and six lower prisms, but the section now generally adopted has eighteen upper and eight lower prisms, Fig 5057, so that the paths of the rays through the prisms are shortened; there is thus less loss by absorption, and greater accuracy is attainable.

The Second Order has an internal diameter of 1·4 mètre = 55·119 in., and a height of glass of 2·121 mètres = 83·525 in. In the old section there were twelve upper and five lower prisms, but the section now generally adopted has sixteen upper and six lower prisms, Fig. 5058.

The Third Order has an internal diameter of 1 mètre = 39·371 in., and a height of glass of 1·56 mètre = 61·435 in., Fig. 5059.

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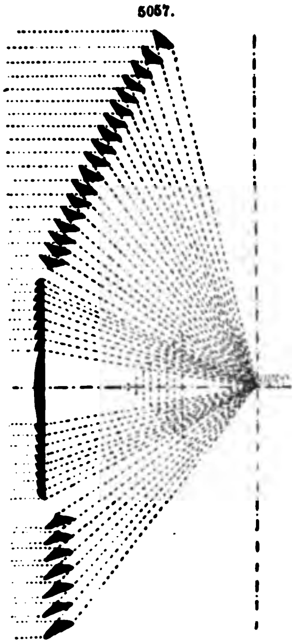

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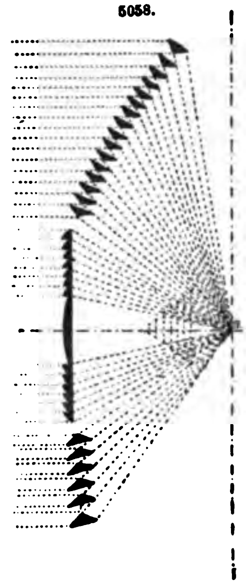

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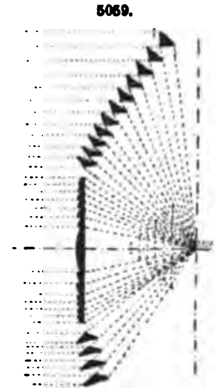

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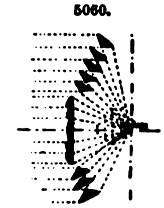

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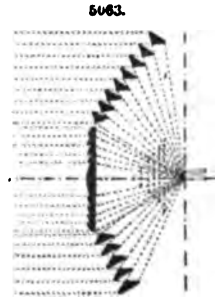

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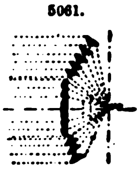

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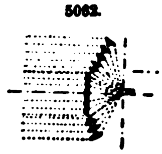

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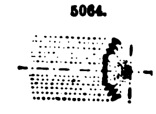

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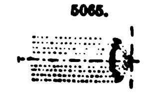


The Fourth Order, being the largest of the harbour lights, has an internal diameter of 0·5 mètre = 19·685 in., and a height of glass of 0·789 mètre = 29·112 in., Fig. 5060.

The Fifth Order, Fig. 5061, has an internal diameter of 0·375 mètre = 14·764 in., all the dimensions being three-fourths of those of the Fourth Order.

The Sixth Order, Fig. 5062, has an internal diameter of 0·3 mètre = 11·811 in., all the dimensions being three-fifths of those of the Fourth Order.

Another order has been introduced between the Third and Fourth, called the Small Third Order, having an internal diameter of 0·75 mètre = 29·528 in., and a height of glass of 1·144 mètre = 45·056 in., Fig. 5063.

In addition to these there have been made the annular lens, shown in section, Fig. 5064, for improving the old reflectors, and called the Seventh Order; and an apparatus, with an internal diameter of 0·15 mètre = 5·906 in., called the Eighth Order, Fig. 5065, which has been used for small fishing stations, ships' lights, and for floating light-vessels.

These various orders relate to the size of the apparatus, and consequently to the power, which is equivalent to the range, since suitable lamps are placed in the focus of each apparatus. Care is therefore necessary in selecting the proper order of apparatus for each lighthouse, as by a too small

order there will not be power enough to light the required distance, and by a too large order there will be a useless expense, not only in the original cost of the apparatus, but also in the lantern, tower, and in the increased maintenance.

The various sections of apparatus already mentioned have been designed to suit oil flames, and the focal lengths chosen have such a relation to the size of the flame as to give a useful amount of divergence.

When petroleum takes the place of oil, if a disc be used in the centre of the circular wick, it becomes necessary to change the position of the foci, to suit the altered shape and condition of the flame. This has been done in France, and with very satisfactory results.

Much remains to be done in the application of petroleum, as at present only burners with one circular wick have succeeded. Petroleum, from the greater whiteness, brilliancy, and cheapness of its flame, and its non-congelation through cold, is sure of a much more extended application than it has at present.

In the electric light, from its condensed size, the focus for all the parts of the apparatus is in a point, and from the shape of the carbon points, as great an angle of light is available below the focal plane as above it.

There are two grand classes of lights, as far as the effects they produce are concerned, namely, fixed and revolving, but there are many combinations of the two plans. The former give a steady light of uniform intensity over the whole arc of the sea required to be illuminated; while the latter concentrate their light into parallel beams which, when the apparatus revolves, produce flashes preceded and followed by an eclipse or total darkness. In fixed lights, not illuminating the whole horizon, means should be adopted to utilize all the light not required in the non-illuminated arc. In dark arcs up to 180°, metallic or glass reflectors are used, but when these arcs are greater than 180°, the excess must be utilized by some other arrangement designed for the particular case, and it frequently happens that vertical condensing prisms, placed outside a continuation of the fixed light, are the most advantageous. When the whole horizon is not illuminated, vertical condensing prisms can sometimes be used for intensifying particular arcs requiring a more powerful illumination, or for showing a coloured light equal in intensity to the adjoining white light.

No general rule can be laid down for the apparatus, as each light has to be designed to suit its particular requirements. The method of determining the shape of a prism by calculation, although simple, is a lengthy operation requiring great care from the number of figures used, and when a design containing a number of prisms has thus been worked out, it generally happens that some modifications are advisable—1, to equalize the sides of the prisms; 2, to suit the framing; 3, to cause the light to miss particular lantern standards. Even if the prisms are worked out from the calculated angles only, the operation is tedious and somewhat uncertain. To obviate this a refraction protractor was designed by Alan Brebner, assistant engineer to D. and R. Stevenson, which enables prisms to be drawn in with great speed and accuracy. After the arrangement has been decided upon, the prisms can be calculated to verify the setting out, and obtain the necessary dimensions for the grinding, without being liable to the inaccuracies of scaling.

Some further modifications have been made in fixed lights to render them intermittent. Thus, at Minehead, in Ireland, the light is visible for fifty seconds at a time; the periods of light being separated by ten seconds of darkness. This result is obtained by means of two screens, surrounding the flame, which suddenly cover and again uncover the flame, the necessary motion being obtained from clockwork placed in the pedestal supporting the optical apparatus. This light is highly characteristic, as there is a long period of light suddenly followed by total darkness, without the waxing and waning of the revolving apparatus; but there is this objection, that no use is made of the light generated during the periods of darkness, so that $\frac{1}{6}$ of the total quantity of oil burnt produces no useful effect.

Oscillating vertical screens have been successfully applied in France, the first application being at the Pointe de Grave Lighthouse, in 1865. H. Lepaute exhibited at Paris, in 1867, a third order, arranged to illuminate 72° of the horizon, with oscillating vertical screens darkening at regular intervals 18° and 25° respectively on each side of the apparatus. The mechanical arrangements were admirable, but no attempt was made to utilize the remaining 288° of light.

The revolving light, however, admits of a greater number of variations, as the flashes may vary from one every two minutes, to one every four seconds. Longer intervals have been adopted but they, as well as the two-minute flashes, are not liked by mariners, on account of the difficulty of identifying the light, and the length of time they are left in the dark. Combinations of fixed and revolving panels are adopted to produce further variety. Colour is applicable to both fixed and revolving lights, but only red, green, and blue are admissible, the former alone being suitable for sea-lights, as the two latter have too limited a range. The amount of light absorbed by the colouring media varies from 55 to 90 per cent., depending upon the colour itself and the depth of tint employed. Red is a valuable colour, as it is difficult to mistake it for any other, and for equal intensities it has the longest range. Even in a fog when white lights are reddened, there will seldom be much to fear, as the mariner is well aware of the fact, and expects to find the white lights reddish, and the red ones rather deeper in tint. The red shades and chimneys used in France are of what is called pink ruby, which absorbs about 57 per cent. of light, whilst the ruby used in this country is called red ruby, giving a deeper tint than the French, but absorbing nearly 75 per cent. of light. Green and blue are only admissible for short ranges, as even in fine weather they cannot be seen far, and the least fog obscures them, more particularly the blue.

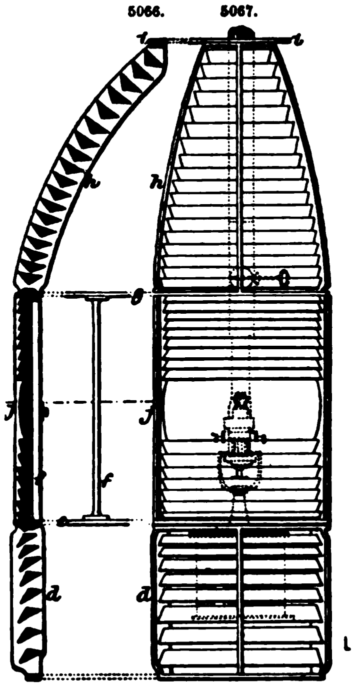
It will thus be perceived that, in fixed lights, there are two useful colours, white and red, by which distinction may be obtained, and these are sometimes employed in the same apparatus to mark particular arcs. Further distinction can be produced by rendering the light intermittent. In revolving lights the same colours are applicable, the flashes may be all white, all red, or combinations of both. Many ingenious arrangements have been carried out in France, for rendering the white and red flashes of equal intensity in the same apparatus, such as proportioning the number of degrees condensed into each beam, and adopting different focal lengths.

In sea-lights, on account of their size and weight, it is necessary to divide the lenses into several portions. The section of the apparatus, consisting of lower prisms, lenses, and upper prisms, gives a convenient division into three tiers, each of which is subdivided into panels of a convenient size. In a First Order fixed light the circumference is divided into eight panels of 45° each, which are made of gun-metal racks, or side pieces, formed to receive the lenses and prisms, these side pieces being connected together with gun-metal segments of rings at the top and bottom.

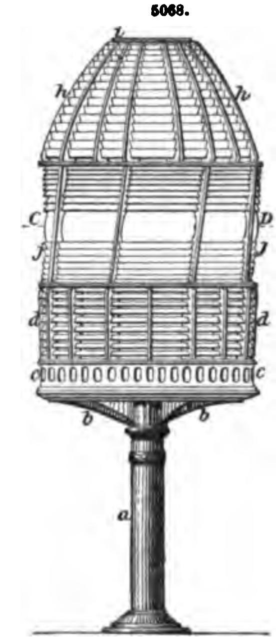
Figs. 5066, 5067, give an elevation and section of one segment of a First Order fixed light. This is the arrangement in general use, all the joints of the panels being vertically over each other.

Fig. 5068 is a general elevation of an arrangement with inclined lens-panels, and the upper prism panels are so placed that their joints do not come vertically over those of the lower prism panels.

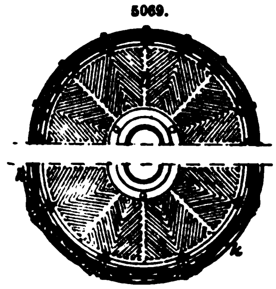
5066. 5067.



5068.



5069.



5070.

5071.

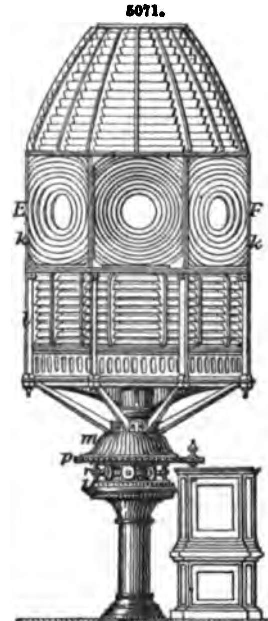


Fig. 5069 gives a half horizontal section through the focal plane of Fig. 5068. In Figs. 5066 to 5068, *a* is a cast-iron column, bolted to the light-room floor, and having its top turned to receive the table *b*, which is free to revolve until the apparatus is placed in its correct position, when it is securely fixed by a set screw. An ornamental balcony *c* is employed to receive the lower prism panels *d*, carrying on their top the connecting ring *e*, on which are erected the standards *f*, one of which is placed behind each junction of the lens panels. When inclined panels are used for the lenses, the standards *f* are also inclined, and stays are introduced, inclined in the opposite direction, to obtain sufficient rigidity. A second ring *g* connects these standards at their upper extremities, and supports the upper prism panels *h*, which are connected together at their top by a ring *i*. This ring is sometimes stayed to the lantern, and forms a support for the ventilating tube. The lens panels *j* are held in their places by small dovetail pieces entering into the top and bottom framing of the lens panels, and secured by means of screws to the rings *e* and *g*. The lens panels are made one millimètre shorter than the distance between the outside of the connecting rings *e* and *g*, in order that no weight may rest upon them from the upper cupola, an arrangement which is of great convenience during construction, as it enables the lenses to be taken down to dry after they are set, and to be out of danger whilst the cupola of upper prisms is being set. At the lighthouse also it affords greater safety to the lenses, because in a storm the whole apparatus is sometimes subject to considerable vibration, and in the case of a lens getting broken, the panel containing it can be taken down and sent for repair without interfering with the rest of the apparatus. In some cases a spare lens panel is supplied. In a few instances the upper prism panels have been made to rest directly on the lens panels. The dotted lines in Fig. 5067 show the position of a First Order lamp and burner.

Fig. 5071 is an elevation, and Fig. 5070 a horizontal section through the focal plane of a First Order apparatus, where the upper and lower prisms are fixed, and mounted as before explained, but the lenses *k* are annular, and mounted on a framework of wrought iron *l*; this revolves outside

the fixed portion, and is bolted to the casting *m*, which receives a rotatory movement from the clockwork contained in the case *n*, by means of the pinion *o*, and wheel *p*, screwed on the outer edge of the casting *m*. The central column, which is fixed, carries the service table, optical apparatus and lamp, and has a projecting moulding upon it about half-way up, which is turned on its upper surface, and fitted with a steel ring *q*, forming the roller path for the friction-rollers *r*. These rollers revolve round the central column, and are retained in their places by a connecting ring and guide-rollers, working round the central column on a turned path. There are several modifications of this apparatus in use, as sometimes only a fixed light is shown in the lower prisms, and the upper prism panels are employed to intensify the flash from the lenses. The number of sides and the rate of revolution are also varied to produce distinction. The arrangement of the clockwork placed at the side of the central column, as shown in this figure, is essentially French; ample strength and solidity are obtained when only the lenses revolve, as the weight is inconsiderable. The cost of this arrangement is less than of that shown in Fig. 5072, where a large square pedestal contains the clockwork.

Fig. 5072 is an elevation, and Fig. 5073 a horizontal section through the focal plane of an eight-sided revolving light, collecting the whole light into eight beams of parallel rays. The usual speed of this apparatus is one revolution in eight minutes, so as to produce one flash a minute, but flashes at intervals of eight and ten seconds have been produced from a similar apparatus, by a slight change in the gearing of the clockwork. *s* is the pedestal with glazed doors, on the four sides, opening to give access to the clockwork. A small column is bolted to the top of this pedestal, which supports the fixed table *t*, carrying the lamps, and forms a guide for the revolving portions of the framework. *u u* are the friction-rollers, working between the steel rings *y*, and secured to a connecting ring, carrying guide-rollers, which work round the central column. As this is the part where the greatest wear occurs, care in detail is necessary. Steel rings and rollers edged with steel, all of the best quality, are fitted with the greatest accuracy, so that an equal amount of work may be done by each roller. Washers of various thicknesses are provided, to allow the course of the rollers to be varied over the roller paths, so as to distribute the wear, and prevent deep grooving. With every precaution there is considerable wear, and it is advisable to construct all the rings in halves, an arrangement which renders their renewal possible without taking down the whole apparatus. Brass rollers have been tried with a view to their receiving nearly all the wear, and thus save the steel rings, but they had this disadvantage, that they wore away so rapidly under the heavy pressure that in a few weeks they had large flat edges, requiring much power to grind them round, and producing an irregular motion which soon resulted in their total destruction. Conical rollers have been tried, but they are not much liked, as from the outward thrust there is a difficulty in keeping the rollers up to their work, and there is a large amount of friction against the ring holding them in. It should be remembered, however, that all these trials were made with roller paths of under 2 ft. diameter, and with the same diameter of rollers as are now generally used, that is, about 5 in. A more favourable result would be obtained from conical rollers with the large diameter of roller paths now used, reducing the outward thrust, and enabling twelve or more rollers to be used to carry the same total weight which formerly was carried by only six. Conical rollers are now being used by Chance, of Birmingham. *v* is a carriage revolving round the central column, upon the friction-rollers *u u*, and receiving its motion from the clockwork, by means of a pinion gearing into the internal gun-metal wheel *w* screwed to the revolving table *v'*. The two castings *v* and *v'* are bolted to each other. On the top of the casting *v'* are bolted eight wrought-iron standards, which carry the whole of the optical apparatus, fitted together in panels as before explained. At the top are guide-rollers *x*, fastened to the upper connecting ring, and working round a turned roller-path, supported by a T-iron framing attached to the lantern.

Fig. 5075 shows an elevation, and Fig. 5074 a horizontal section through the focal plane of a First Order apparatus, commonly called a fixed light varied by short eclipses, a title which certainly does not state the actual effect, namely, that of a fixed light followed by an eclipse, a flash, and an eclipse, the same phases being continually repeated. The apparatus consists of four sides, of 45° each, constructed as for a regular eight-sided revolving light; four complete segments, of 45° each, of a fixed light, as in Figs. 5067, 5068, are fitted in between them, and the whole is mounted on a revolving carriage working on a fixed pedestal, as already explained. If the apparatus revolve once in eight minutes, there will be one minute of fixed light, twenty-six seconds of eclipse or darkness, eight seconds of flash, and twenty-six seconds of eclipse, followed by a repetition of the same. In many of these revolving lights it is customary to leave out one of the lower prism panels, so as to afford access to the lamp, but in some cases a hinged panel is used, and in others sufficient height is given to pass underneath, as in Fig. 5076. In fixed lights illuminating the whole horizon, access can be had through a man-hole in the service table. Revolving lights are made of eight, twelve, sixteen, and twenty-four sides, to enable the intervals between and the intensities of the flashes to be regulated.

In Second Order fixed lights, the panels are made of 60° each, and revolving lights have eight, twelve, and twenty sides.

In Third Order fixed lights, the panels are made of 72° each, and revolving lights have eight, twelve, and sixteen sides. The number of sides may of course vary from those given, and it will be for the engineer to determine the number suitable for the requirements of the lighthouse about to be erected.

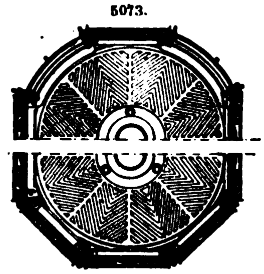
The method of framing Second and Third Order lights, both fixed and revolving, is similar to that adopted for First Order lights.

Harbour lights, from their small size, are generally fitted together in one piece. Figs. 5077, 5078, give a sectional elevation and sectional plan through the focal plane of a Fourth Order fixed light illuminating three-fourths of the horizon, the remaining one-fourth having a silver-plated reflector. The lamp shown is a moderator, placed upon an adjustable stand for regulating the position of the

burner. Figs. 5079, 5080, are an elevation and sectional plan through the focal plane of a six-sided revolving Fourth Order, mounted on a square pedestal containing the clockwork. The French

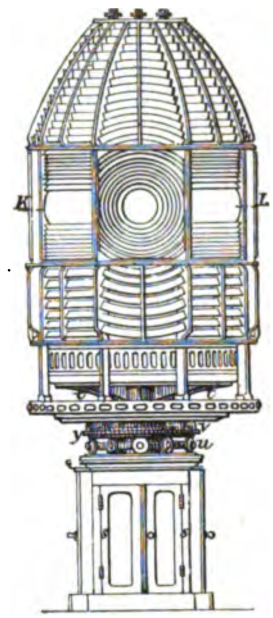
5072.

5073.

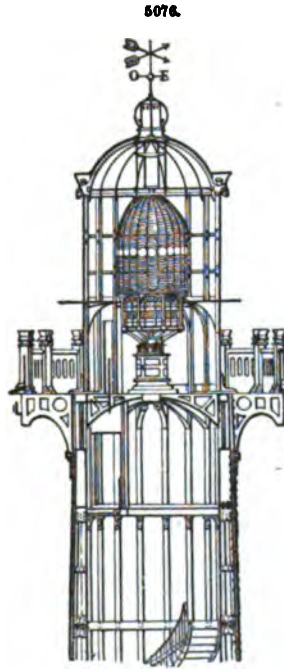


5074.

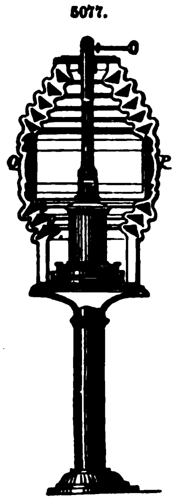
5075.



5076.

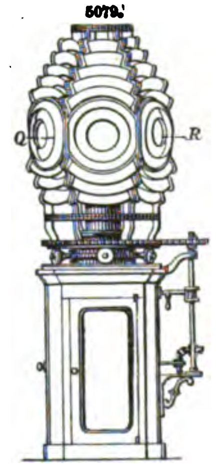


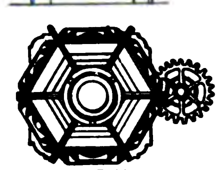
5077.



5078.

5079.





5080.

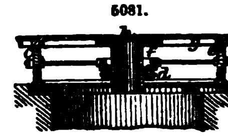
arrangement of placing the clockwork at the side, and of having a small column to carry the apparatus, is in some cases convenient, in others necessary, on account of the small size of many harbour lanterns.

The construction of panels for the old lights was more complicated than the present method, as there was a regular framework or armature of wrought iron, between which the panels were fitted. This framework caused great loss of light, from the joints sometimes having a thickness of 1⅝ in.

or 2 in. The distances from the wrought-iron standards to the indented edges of the panels were filled in with gun-metal, and in the English apparatus no chipping pieces were used, so that the weight of gun-metal, and the cost of fitting, were much greater than in the modern method. D. M. Henderson advocates a reduction in the thickness of the sides of the panels, to economize light and gun-metal, and to enable all, or nearly all, the framework to be arranged by machinery in place of by hand. The indented or serrated racks were troublesome to fit, owing to the large extent of edges requiring to be accurately made to correspond. By the method now adopted, and shown in the First Order apparatus, much fitting has been saved, and, by casting the side racks recessed, with only a chipping fillet run round the edges, an economy of metal results, and increased rigidity is obtained in the panels. Lining plates of gilding metal about $\frac{1}{16}$ in. thick are used to finish off the ends of each panel, and hold in the prisms; at the same time they cover all the recesses, giving the same appearance as if the racks were solid. The intermediate racks cannot be recessed, as there is no covering plate, but the thickness is only about $\frac{3}{4}$ in., and they weigh less than the former thick indented ones. If desired, there is no reason why these latter should not be cast indented as before. The racks are planed on both sides; the outer edges are filed, and the apertures for the prisms, when the castings are accurate, only require cleaning up. The upper and lower connecting rings are turned in one piece, or in segments fitted together. To make a panel, two racks or side frames are butted against the upper and lower segments of rings, and after a couple of wrought-iron screws have been put into each joint, the whole is soldered together, and, in the panels which have an intermediate rack, it is afterwards added in a similar manner. After the panels are made, they are erected upon a table, having its upper surface turned and placed perfectly level, with a round centre rod accurately fitted in a socket, so that its centre corresponds with the vertical axis of the apparatus to be erected. By means of gauges, with semicircular ends fitting round this centre bar, and resting on adjustable collars, the panels are fitted in their places, and the holes marked out for the screws to hold the whole together. By the use of templates, and the accurate machine-work now applied to all the meeting surfaces, panels can be made interchangeable, which was impossible in the old arrangement of armatures produced by hand. The amount of clearance round each prism is $\frac{1}{8}$ in., to allow for adjustment in setting the prisms, and for the putty used to secure the glass.

When the fitting is finished, the panels are taken to the erecting shed, where they are erected on their pedestals, or on what is more convenient, a revolving table, specially constructed so that each panel, or part of a panel, can be brought in succession opposite the erecting post. An arrangement of erecting table is shown in Fig. 5081, where a is a ribbed cast-iron bed-plate, with a turned pathway b on its outer edge for the friction-rollers c, and another turned pathway on its vertical central shaft, to form a pathway for the guide-rollers d. The top table g has a similar roller path e, and guide-rollers f on its under side, and the top is turned and pierced with holes to enable the various sizes of apparatus to be secured to it. A wrought-iron plate h covers the central aperture, leading into a pit prepared for the reception of the driving weights of a rotatory machine, or mechanical lamp. As the operation of setting the glass produces much débris, from the plaster of Paris and putty used in fixing the prisms, the erecting table should be designed to protect the friction and guide rollers as much as possible from the dust. Apertures are provided in the bed-plate to afford access to the guide-rollers, and enable the whole of the interior to be cleaned without lifting the upper table. The inclined roller paths do not accumulate dirt, and do not require oiling. The prisms are passed into their places, one end covering plate of the panel to be set being removed, and wooden wedges are used to support the glass, and enable it to be accurately adjusted in its position by means of internal observation. When the prisms are adjusted, plaster of Paris is applied at all the corners to retain them in their correct position, and when it is fairly set the wedges are removed, and the remaining spaces filled in with best red-lead putty. In the lens panels, as glass butts upon glass with only a thin film of cement intervening, there is no means of adjustment such as exists in the case of the prisms. The only method is to build up each lens panel, beginning at the bottom, and to make each ring correct before another ring is superposed. This latter fact has, up to the present time, prevented any attempt being made to readjust the lens panels in those lights whose upper and lower prisms have been readjusted, as this could only be done at the manufactory. The readjustment of defective lights is a point of importance, for by a small outlay, for a First Order apparatus, a great improvement has been effected, and a good result obtained from the upper and lower prism panels, which frequently threw all the light falling on them where it was impossible to be seen. The effect of the lens panels in many lighthouses can be, and has been, improved by placing all the centres in one level plane, with the inner surfaces vertical, and then putting the burner in its most advantageous position, in the centre of the whole combination.

5081.

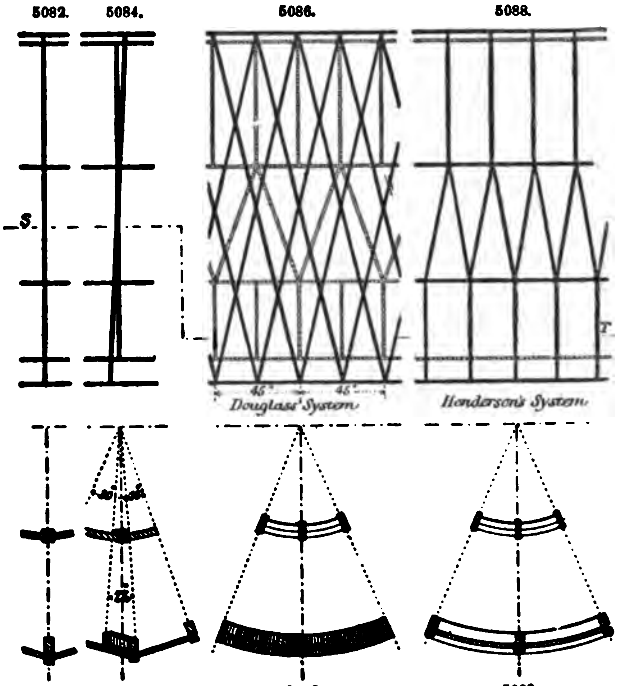


The arrangement of panels generally adopted is that of placing one panel over the other, so that the joints come vertically over each other; and it has in its favour—simplicity, a minimum loss of light, a minimum cost, and strong convenient-shaped panels. These advantages have been considered of such importance that in France the above method is still adhered to, and all the lanterns are constructed with vertical standards placed in front of the obscuration caused by the sides of the panels. Figs. 5082, 5083, represent in elevation and plan this arrangement, which has the disadvantage of causing as many points, or rather small arcs, on the sea, as there are standards in the lantern, to be illuminated with a considerably weaker light. In front of each standard of a First Order lantern the light is weakened from 30 to 57 per cent., according to the thickness of standard employed, and there will be sixteen points on the horizon, when it is all illuminated, receiving this weakened light. In harbour lights the obscuration is frequently greater, on account of the small diameter of the flame, and the thickness of the standards. Alan Stevenson, aware of this defect, was the first to introduce inclined lens panels, with a view to equalize the distribution of light on the sea, but he was well aware, no doubt, that there would thus be a diminution of light.

Several lighthouse authorities adopted a lantern with inclined standards, thinking to obviate the difficulty connected with vertical standards, but no alteration was made in the construction of the optical apparatus. Figs. 5084, 5085, represent, in elevation, the effect of an inclined standard projected upon the apparatus, and in plan the actual position is given. The horizontal divergence, resulting from the size of the burner, may be taken at 6°, and the standard is inclined over an angle of 7½° in plan, so that when an observer is placed in front of the standard, it nearly stops off the light from him throughout its entire height, commencing on one edge of the flame and finishing on the other, thus obstructing much light which had successfully passed through the apparatus. The defects of this system are apparent, as more light is stopped without there being any greater uniformity, and a more costly and unsightly lantern is obtained. The French engineers have always seen and avoided this error.

The lantern of J. N. Douglass is designed to render impossible a correspondence, or optical coincidence, between the framing of the apparatus and that of the lantern. The effect is shown in Figs. 5086, 5087, where the shaded portions represent the framing of the optical apparatus, and the thick black lines the lantern framing. The framing of the apparatus stops 4·5 per cent. of the surface of the apparatus, and the framing of the lantern 6·8 per cent. of the surface of the lantern glazing, and as the two obstructions do not coincide, the total loss becomes very serious. These lanterns are expensive, from the amount of workmanship of a costly class, and from the quantity of glass cut to waste.

5082. 5084. 5086. 5088.



5083. 5085. 5087. 5089.

To obviate the objections of the previous methods, D. M. Henderson designed the following arrangements.

The first consideration is the optical apparatus, and it is apparent that a minimum amount of light is stopped by vertical panels, and that it is possible to divide the previous large obscurations into a greater number of smaller ones; thus equalizing the light without in the slightest degree increasing the total obscuration. By excentering or placing the various tiers of panels so that their joints do not come vertically over each other, each previous obscuration is divided into three; the amount of excentering necessary depends upon the size of the flame, but it should be such as to enable one obscuration to be completely passed before entering upon another. In the First Order, for example, each panel subtends an angle of 45°; and, as there is an intermediate rack in the prism panels, there is an arc of 22½° between each obscuration. Each large obscuration can be divided into three small ones, which, if placed at intervals of 7½°, will never allow more than one obscuration to be visible at a time, as the divergence of the flame is under 6°. No practical difficulties or extra cost are involved in this arrangement.

The next consideration is the lantern, which, when arranged with excentered panels, is rendered less rigid, owing to the weight not being transmitted continuously downwards as is the case with vertical standards. This want of rigidity would be objectionable for a light illuminating the whole horizon, but in those illuminating from 180° to 270°, which are by far the most common, the objection might be easily overcome, as the dark arc could be filled in with solid iron plates, by which great rigidity would be obtained. When the frames are riveted together and the ¼-in. curved plate glass is in its place, additional strength will be obtained.

By the substitution of triangular frames in the central tier, it is still possible to retain the upper and lower panels excentered, and to render the framing perfectly rigid, in fact more so than with the vertical continuous bars of the old lanterns. This latter arrangement is peculiarly adapted for the employment of inclined lens panels. The result is shown in Figs. 5088, 5089, where the shaded portions represent the framing of the optical apparatus and the thick black lines the framing of the lantern. Much light is saved by the coincidence of the two sets of framing, as when a lantern standard is placed in front of a junction of the panels in the apparatus it will stop a little light, as the diameter of the flame is greater than the thickness of the joints of the panels. This will not happen in the case of the electric light placed inside a large apparatus.

The sole object of a lantern is to enclose an optical apparatus, and prevent its being damaged by wind, water, or birds, so that the maintenance of a perfectly steady and high flame may be ensured. The lantern should be designed to suit the apparatus, care being taken to get the

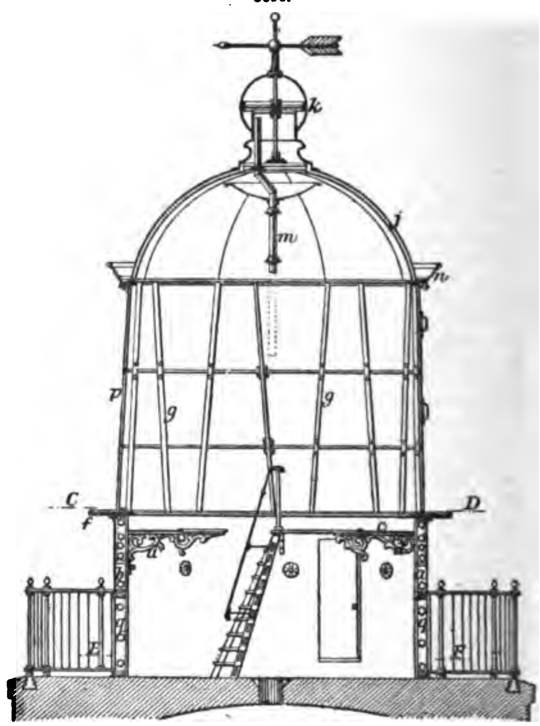
necessary strength with the least possible obscuration of light, and its size should be such as to afford ample space for the light-keeper to attend to his duties, at the same time avoiding too great size as a useless waste of money, which would be much better spent in establishing other lighthouses in localities destitute of them.

SIZES OF LANTERNS IN GENERAL USE.

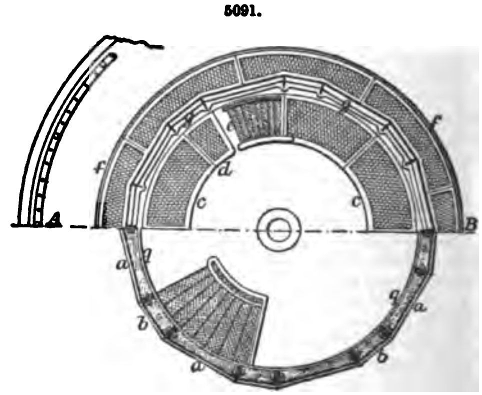
Order.	Number of Sides.	Internal Diameter of Light-room.	Height of Glazing.	Height of Focal Plane above Light-room Floor.
		ft. in.	ft. in.	ft. in.
1	16	12 0	10 0	11 6
2	12	10 0	8 0	10 10½
3	10	8 0	5 6	8 10½
4	8	6 0	3 6	4 7½
5	8	5 0	3 0	4 6
6	8	4 6	2 9	4 6

The lantern proper consists of the framing for the glass, the plate glass, a sole plate, an inner service gallery, with the necessary brackets to support it, steps to lead from the light-room floor to the service gallery, and the cupola complete with the cowl. In the case of stone or brick towers the light-room is frequently built of the same materials; but sometimes in stone, and always in iron towers it is constructed of wrought or cast iron. Fig. 5090 represents a sectional elevation, and Fig. 5091 a half sectional plan through the glazing, and a half sectional plan through the light-room, of a First Order lantern with inclined standards. The light-room is composed of sixteen cast-iron plates, eight large ones *a*, subtending an angle of 30° each in plan, and eight small ones *b*, of 15° each, fitted together to form a circular chamber of 12 ft. 2 in. internal diameter, and an irregular polygon outside about 13 ft. across the corners. These light-rooms are frequently lined with mahogany, pine, or corrugated iron; a wood lining *q* is shown in Figs. 5090, 5091, 1 in. thick, reducing the internal diameter to 12 ft. Eight ventilators, one in each small side, are generally employed, the construction being such as to prevent water entering, and with gun-metal hit and miss valves the supply of air can be regulated at will. The service gallery *c* is of open cast-iron plates carried on brackets *d*, bolted in between the flanges of the blocking, and steps *e*, provided with a hand-rail, lead from the light-room floor to this gallery. A sole plate *f* is fitted on the top of the blocking, forming at the same time an outer gallery for the light-keeper to stand upon whilst cleaning the outside of the glass. The standards *g* are sixteen in number, alternately inclined in opposite directions, so that the large side at the bottom becomes the small side at the top, and the reverse; they are made of wrought iron, having feet passing down between the flanges of the blocking plates, to which they are secured by a couple of bolts for each foot. Two sets of horizontal gun-metal astragals *h* divide the lantern into tiers corresponding with the divisions of the optical apparatus.

5090.

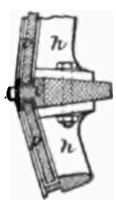


5091.



strengthen the framing, and assist in securing the plate glass. The standards are united at the top to a wrought-iron connecting ring, to which are attached the rafters *j*, about 1⅛ in. square, covered in with an outer roofing of copper 3 lbs. to the square foot, and an inner roofing 1⅜ lb. to the square foot. This inner roofing is sometimes of zinc or galvanized sheet iron. The cowl *k* is a revolving one of sheet copper, mounted on a spindle working in an oil cup at the bottom of the neck, and underneath is placed a hollow dish to prevent any drops of water that might accumulate inside the cowl from falling on the apparatus. A ventilating tube of copper *m* conducts all the products of combustion direct into the cowl, where they pass out by a number of 1-in. holes, which are always turned from the wind by the vane on the cowl-spindle. The gutter *n* is of sheet copper, provided with a stiffening wire at its upper edge, and gun-metal joint-covers. A copper ladder rod is fixed to the under side of the gutter, and inside the lantern a similar rod or hooks are provided for the curtains. The glazing is of ⅜-in. plate glass *p*, which is secured in its place by gun-metal strips and screws, and two tiers of handles facilitate its cleaning. Rain-water pipes, fitted in front of two of the standards, convey the water from the gutter to the foot of the lantern. Figs. 5092, 5093, are details of a standard *g*, showing the connection with the astragals *h*, and how the glass *p* is secured. A facing strip of gun-metal *i* is screwed to the standard, so that the glass rests in a gun-metal groove, and all the screws securing the strips which hold in the glass are screwed into gun-metal, and are consequently easily removed in case of a pane being broken. Fig. 5094 shows a detail of the lower gun-metal sill *o*, resting on the sole-plate *f*, which is bolted to the top of the blocking *a*. The mahogany lining *q* is secured to pine packing pieces *r*, wedged in between the flanges of the blocking. This lantern is objectionable, on account of the too small inclination of the standards and their non-coincidence with the joints of the optical apparatus. The large flat sides are ugly, and those of the blocking are easily broken, on account of the small depth of flange at the centre of the plate compared with that at the sides. The cost is increased by the more difficult workmanship, by more glass being cut to waste than with vertical standards, and from the fact that six different sizes of panes are used in place of three.

5092.



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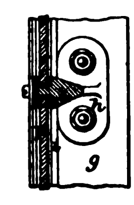
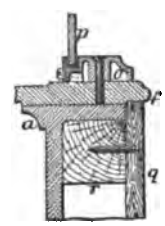


5094.



The French adhere to one form of lantern for all apparatus burning oil; a description of which may be of interest, to enable a comparison to be made with the lantern previously described. The example selected is the First Order lantern, Fig. 5076, designed for the Roches Douvres, about half-way between the islands of Guernsey and Bréhat. The lantern standards are vertical, sixteen in number, and extend in one piece from the cornice to the bottom of the light-room, which is formed of wrought-iron covering plates screwed to the standards and to the framing connecting them. The standards are faced with gun-metal, and have gun-metal astragals, upper and lower sills to receive the plate glass, and ventilators fitted all the way round in the lower sill. The under portion of the cornice forms the gutter, which conducts the rain-water to a lion's head placed over each standard; while the upper portion is of open work, which improves its appearance, and hides the little ventilating boxes placed in the gutter. The cowl is fixed, and is provided with a movable vane to indicate the direction of the wind. The roof and all the parts exposed to the sea above the light-room are of gun-metal or copper. The roof is supported on a regular framework of iron, which also carries the steadying cylinder for the optical apparatus. The apparatus has twenty-four sides, and makes one entire revolution in 1 minute 36 seconds, so as to give a flash every four seconds. This great speed necessitated a special construction of clockwork, which was successfully accomplished by Henry Lepaute, who constructed the whole apparatus and lantern. The total weight of the revolving portion is 2 tons, and the driving weight 121 lbs., falling 66 ft. in six hours. The regulator is the centrifugal one invented by Fresnel, and afterwards improved by Lepaute. The section of glass consists of nineteen upper prisms, a central lens, with eight lens rings both above and below, and eight lower prisms. A mechanical lamp burning colza oil is used, and the intensity of the flash is estimated at 2475 becs carcels. The whole of the armature was constructed with the least possible weight, to save the friction-rollers, and sufficient height was given to enter the apparatus without omitting, or suspending on hinges, any of the lower panels.

Figs. 5095 to 5098 are an elevation and plan through the glass, and a half sectional plan through the blocking, of an arrangement of lantern designed by D. M. Henderson to remedy the defects of previous lanterns.

The apparatus, Fig. 5068, is arranged for the most uniform distribution of light practicable; and the lantern here described is capable of being put round that apparatus with only a small obstruction of light. The blocking is circular, of cast iron, but it may be of wrought iron, with wooden or corrugated galvanized iron lining; and sixteen ventilators are employed, one in each segment. An inner service gallery is carried on brackets, and a sole-plate with outer cleaning path, rests on the blocking. It is preferred to make the framing of forged iron or steel, but it may be of cast iron. The quadrilateral frames in the lower tier are fitted together with vertical joints, and form a level surface on which rest the triangular frames of the middle tier, again forming a level surface for the upper tier of quadrilateral frames. A cast-iron gutter is shown, as it can be easily connected with the framing, rafters, and roofing plates, thus doing away with a considerable amount of work.

Fig. 5097, a detailed section of the framing, and manner of securing the plate glass by gun-metal capping.

Fig. 5098 shows in detail the connection between the framing, gutter, rafters, and roofing plates. There is a much larger air-space than usual, and the rafters have apertures in them to

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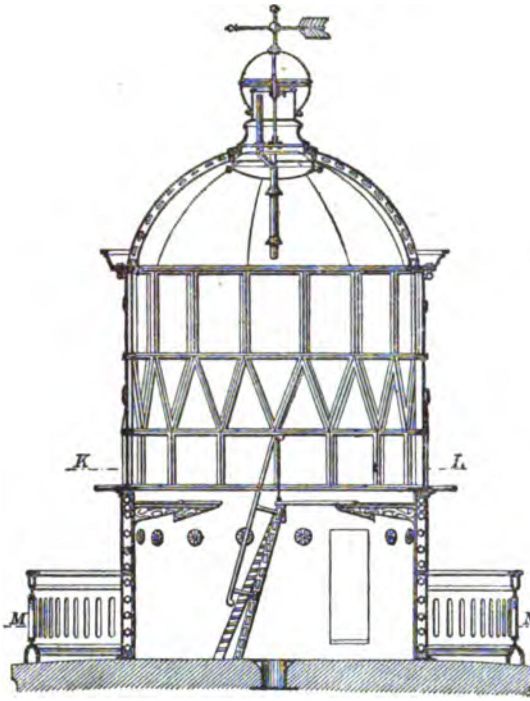

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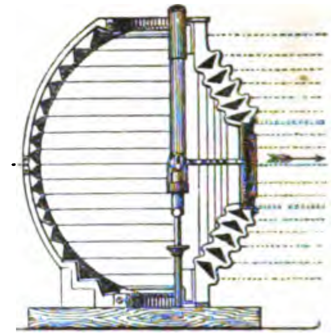

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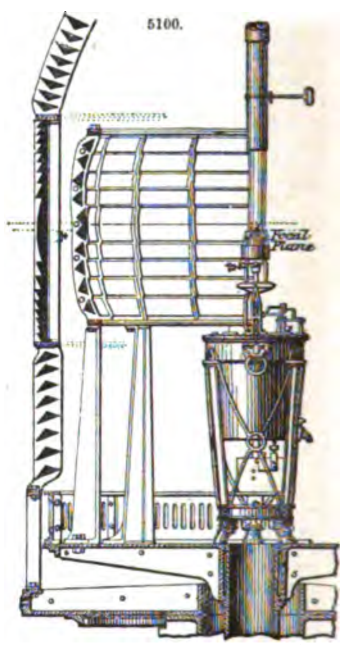

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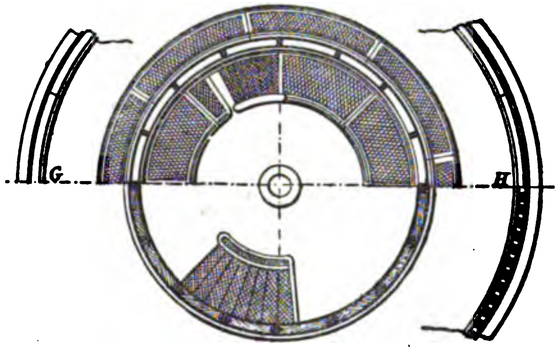

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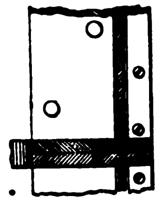

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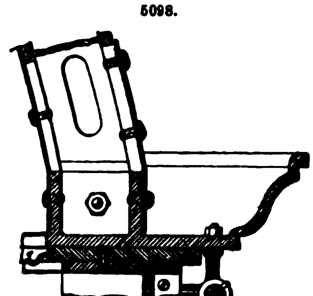

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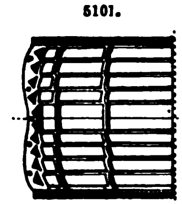

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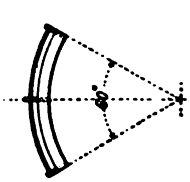


enable the air to circulate freely. Circular glazing is preferable to flat, on account of its greater strength, and as being better calculated to resist the action of the wind; besides the rays of light pass normally through it.

Fig. 5099 is of the first catadioptric mirror ever made, and which was used by the Stevensons in conjunction with a Sixth Order holophote, to condense the whole of the light from an argand burner into a beam of parallel rays. The internal radius was 12$\frac{1}{16}$ in., and the thickness of the joints was $\frac{1}{16}$ in. Sufficient space was left at the top and bottom for the passage of the damper tube and burner of the lamp. In this case the mirror was constructed of flint glass, whilst crown glass was used in the construction of the holophote. The employment of flint glass was costly, as it had to be specially made, and great accuracy was necessary in jointing the various pieces together.

Thos. Stevenson originally designed these mirrors with the zones generated round the horizontal axis; but in this instrument James Chance introduced for the first time the plan of forming the zones round the vertical axis, being that of the flame. The advantages of this latter plan are important optically, in addition to facilitating the construction of the zones themselves, and enabling the mirror to be easily limited both vertically and horizontally.

In Chance's mirror the zones are separated and divided into segments like the ordinary reflecting zones of a dioptric light; thus the radius of the mirror is considerably increased, and it is applicable to the largest sea-light, without overstepping the limits of the angular breadths of the zones, and without being compelled to resort to glass of high refractive power.

The separation of the zones also renders it feasible to avoid giving to the aggregate structure a spherical shape, which encroaches most inconveniently upon the space required for the service of the lamp.

In determining the sizes of the mirrors, the chief consideration was to arrange as few sizes as possible, in order to diminish the cost by the small stock of glass, moulds, and gauges that would be required, and to enable them to be used in revolving as well as in fixed lights.

Fig. 5100 shows a sectional elevation of a First Order mirror placed inside a revolving light of the same order. The internal radius is ·75 mètre, and the panels are ordinarily constructed of 45° in plan, so as to correspond with those of the apparatus. This size is equally applicable for both fixed and revolving lights.

Fig. 5101 is a sectional elevation of 90°, and Fig. 5102 a plan of one panel of 60° of a mirror of ·6 mètre radius, which is applicable to Second Order fixed and revolving lights, and to Third Order fixed lights. The construction of these panels is similar to that already described for the prisms, and in general they are secured to cast-iron brackets, which are bolted to the service table of the apparatus, as shown in Fig. 5100.

The lamps employed are of great variety, but all have the same object, to give a regular and abundant supply of oil to the burner.

In the sea-lights the following sizes of burners are generally adopted;—

Order of Apparatus.	Number of Wicks.	Diameter of Burner in inches.	Intensity in becs carcels.	Consumption an hour in lbs.
1	4	$3\frac{1}{2}$	23	1·677
2	3	$2\frac{11}{16}$	15	1·103
3	2	$1\frac{3}{4}$	5	·386

In the Fourth Order, a two-wicked burner, about $1\frac{3}{16}$ in. diameter, is used; but in the Fifth and Sixth Orders, single-wicked burners are generally employed, consuming from 0·17 lb. to 0·1 lb. an hour. The French have recently constructed a moderator lamp with two wicks, for the Fifth Order, which has considerably increased the intensity of light.

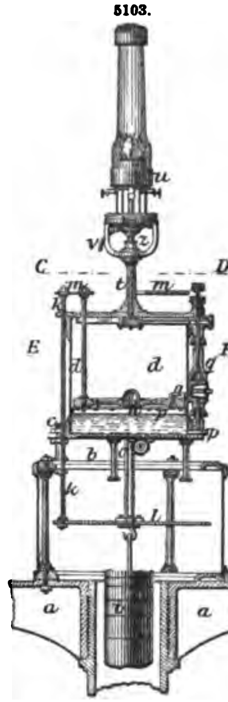
In most of the Scotch lighthouses, there is a larger consumption of oil than is given in the above Table, and consequently a greater intensity of light is obtained.

The three principal varieties of lamps now in use for sea-lights are the mechanical, the high reservoir, and the pressure. The mechanical are the most general, being adopted in Scotland, France, and many other countries. The most perfect is that employed by the Stevensons, and manufactured by Milne of Edinburgh. A sketch of this lamp is given in Fig. 5100. The French mechanical lamps also give excellent results. The oil, in both cases, is forced over the burner by pumps, which are worked by clockwork placed underneath and driven by a weight.

The high reservoir lamps have many varieties. One of the best is that designed by Captain Nisbet, of the Trinity House, and successfully applied to several English lighthouses. In this lamp the body is of copper, hammered to a vase shape, with plunger-pumps inside to force the oil up to the high reservoir, from whence it descends to the burner by gravity, a fountain arrangement being provided, so that the pressure is always constant. The high reservoir is fixed to the armature in the non-illuminated arc, at such a height as to give a head of 6 in. or 12 in. of oil. If a greater head is employed, the pressure necessitates the regulating valve being nearly closed, and thereby rendered more liable to be choked up by flock from the wicks or other foreign matter. The feed-pipe passes down to the service table and under its surface to the centre of the apparatus, where it mounts through the lamp-body to the burner, and the supply-pipe for the high reservoir passes side by side with it. Excellent provision is made for regulating the overflow by an indexed regulator worked by a thumb-screw, and at the outer edge of the service table are placed cocks for drawing off all the oil. These lamps are costly, and are not applicable to revolving lights or those illuminating all the horizon, on account of the obstruction of light caused by the high reservoir. This is a defect common to all lamps of this class.

Fig. 5103 is a sectional elevation on line A D of a pressure lamp, upon **Masselin's principle**, equally well adapted for fixed and revolving lights, whether the whole horizon is illuminated or not. Fig. 5104 is a plan of the burner; Fig. 5105, plan on line C D; Fig. 5106, on line E F; and Fig. 5107, bottom of cylinder and stand. *a* is the service table, upon which is bolted the lamp-stand *b*, having upon its upper ring three screws *c*, for holding and regulating the position of the lamp. The apertures in the bottom flange of the lamp are large, so that room is provided for accurately adjusting the lamp in the centre of the apparatus. The body of the lamp *d* is made of a cylinder of sheet brass fitted into an upper and lower cast-brass ring, the whole being turned and bored previous to tinning the inside. The boring of the lamp-barrel is essential, as by that means, and the turning of the piston *e*, so little room is left between them that it is impossible for the cupped leather packing *f* to turn over. The piston is of cast iron, and has six guides *g* of leather, fitted edgeways between cheeks, so as to maintain the piston in the centre. A valve *h* is fitted in the centre, opening downwards, when the piston is raised, and facilitating the passage of the oil to the under side of the piston. It at the same time prevents the accumulation of air under the piston, as the valve only closes when the piston reaches the oil. A fine wire gauze is placed on this valve to exclude pieces of wick which might, through carelessness, enter the body of the lamp. The weights *i* are of cast iron, in discs, so that the weight can be varied at will; and connecting rods *k*, attached to the plate *l* at their bottom, and a ring *m* at their top, with a second set of connecting rods, apply the weight to the piston. All these connecting rods act as guide-rods, by being passed through holes in the cylinder and cylinder cover. The weight is raised by a handle fitting loose on the horizontal spindle *n*, under the body of the lamp. This spindle carries two pinions gearing into the racks *o*, which are attached to the plate *l*, and work in guides cut in the flange of the cylinder bottom. A tap *p* is provided for emptying the oil, and *q* is the feed-pipe, for conducting the oil to the burner, containing the valve *r* and regulator *s*. The feed-pipe passes under the cylinder cover and up the central column *t* to the burner *u*. The overflow oil passes over the burner, and is collected in the cup at its bottom, and conducted by a pipe *v* to the strainer *w*, composed of a fine plate of perforated tin, with fine wire gauze underneath, so that no flock or charred wick can enter the lamp cylinder. The valve *r* is cylindrical, with two apertures opposite each other, and when these are vertical the oil can pass to the burner, but, by turning the cylinder slightly round, the passage is closed, and the cylinder cover may be taken off—only the oil contained in the valve being spilt —when the cross filter can be cleaned, or removed and replaced by another, the whole being easily readjusted in a couple of minutes. To prevent the tendency to draw down the oil from the burner during the winding up, a self-acting spherical valve *x*, of some light material, is placed over the cylindrical one, so as to close whenever the piston begins to be raised, and remain so till the piston is released. The regulator *s* consists of a conical point which enters the feed-pipe, the distance it enters being regulated by a fine-threaded screw, and facilitates the regulation of the overflow. An index is placed so as to enable the light-keeper, by inspection, to know the position of the regulator. Safety fountains are sometimes sent with these lamps, so that in case of an accident to the main lamp they can be filled with oil and set to work in a few minutes, by coupling their supply-pipe to the union joint *y* of the lamp. The burners are screwed to the central column by the union joint *z*, and they are further steadied by a holder clipping the cup of the burner, which is of brass, accurately turned. By unscrewing two screws the burner can be detached and replaced by another always kept ready in the light-room. The burners are interchangeable, and are all made to standard gauges, the concentric holders for the wicks being of sheet iron, brazed, and then tinned. Each wick has two small feed-tubes, one on each side, so as to ensure an abundant supply of oil. The bottom of the burner is movable, so that access can be had to the interior, for the purpose of cleaning the supply-tubes. A chimney-holder of brass fits over the burner, and its position is regulated by means of a couple of racks and pinions, to enable the light-keeper to place the shoulder of the chimney at the proper height, a point of great importance in the production of a good flame. The wicks are raised by small racks and pinions fitted to each wick-holder, and a number is conspicuously placed on the thumb-screw of each, referring to the number of the wick. To produce a good flame it is necessary to have an overflow of from three to four times the consumption and the greatest care must be taken to light up slowly, so as not

5103.



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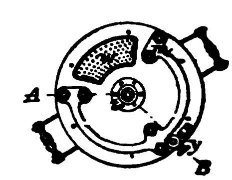

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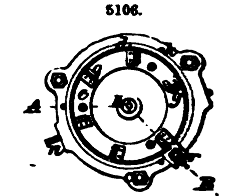

5107.

to char the wicks. With care a good flame may be kept up for seventeen or eighteen hours without trimming. For harbour lights, moderator or fountain lamps are generally used, and sometimes the reservoir is placed over the apparatus. A good overflow, however, should be maintained, as in the sea-lights, otherwise the wicks char, and after a few hours cease to give a good flame. A damper tube is placed over each chimney, and the ventilating tube generally employed is the one introduced by Faraday with such excellent results. The chimneys are of flint glass, about $\frac{1}{16}$ in. thick, carefully annealed, and it is important to give the correct form to the shoulder, so as to ensure the production of a good flame, and to obstruct as little light as possible.

Figs. 5108, 5109, are side and end elevations of a First Order clockwork, consisting of two trains of wheels, one for driving the apparatus, and the other for driving a fly-wheel with adjustable vanes

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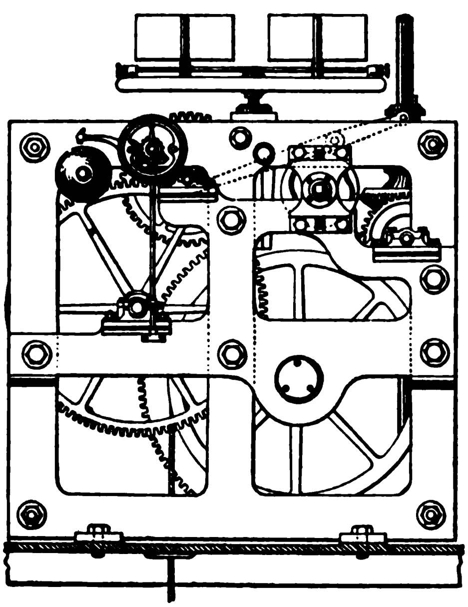

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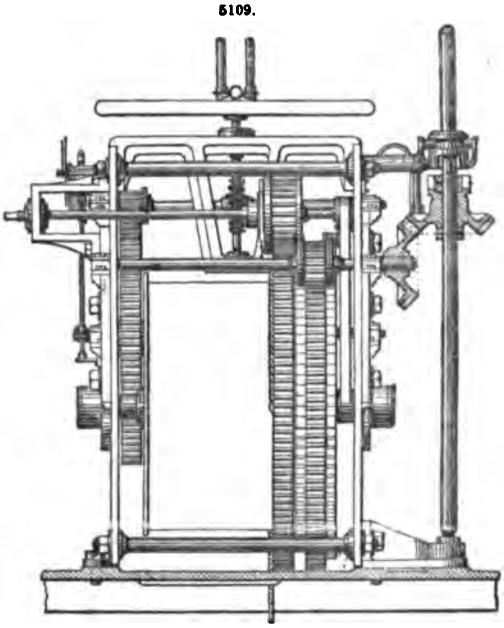


for regulating the speed. The driving weights are suspended by a rope wound round a barrel. Experience has proved that the wide barrel was objectionable, as the weight could not be passed directly down a small central column; the rope wore out rapidly, and frequently let the weights fall; the method of driving the fly-wheel absorbed a large amount of power, and caused difficulty in keeping the apparatus at its correct speed. To obviate the first two of these objections, Henderson introduced a chain working in a toothed pulley, enabling the weight to be passed directly down a central column. The chain was durable, and not affected by moisture like the rope. The pulleys and chains employed were similar to those made for Weston's differential pulley blocks. This method has been used in many clockworks, but it requires great accuracy in the size of the links of the chains, otherwise slight jars are produced when the links leave the pulley. All the advantages of a chain might be got from a wire rope with Fowler's clip-drum. By employing an endless chain or wire rope, a constant driving power is obtained, which is not the case with an ordinary barrel arrangement. To obviate the third objection, recourse was had to the French plan of driving the fly-wheel, by means of a bevel-wheel gearing into a small bevel lantern pinion on the fly-wheel shaft. There is, however, no necessity for a fly-wheel, which is replaced in most of the French clockworks by a self-acting governor on the Fresnel or Foucault system. An indicating hand is arranged to make one revolution an hour when the clockwork is going at its proper speed, so as to admit of comparison with the light-keeper's clock. A small supplementary weight was sometimes used to maintain the clockwork at its correct speed during the winding-up, but the plan was not self-acting, and required space for the falling of the weight.

Buoys and Beacons.—Floating beacons may be divided into two classes, according to the service for which they are designed;—

Beacon buoys, which are placed in exposed situations, to mark the position of sunken rocks, sandbanks, wrecks, or similar matters dangerous to navigation.

Channel buoys, which are used for defining the navigable channels of rivers.

It is of essential importance that all buoys, but more especially those used for sea-marks, should be conspicuous in all states of the weather; and for this purpose,

The superstructure should be erect, well raised above the surrounding water, and presenting a considerable breadth of surface, so as to be conspicuous at a distance. Hence stability is an essential quality.

The buoy should present a steady object to the view, and be as free as possible from rolling, and more especially from abrupt pitching, which not only tends to snap the mooring chain, but

also prevents the seaman from deciphering any name or characteristic mark which may distinguish the buoy, and define its position on the chart.

The earliest buoys were, probably, barrels or large casks, and this form is still retained in channel buoys. When the barrel buoy is made of iron, the ends, instead of being square, are slightly rounded, so that the buoy resembles a woolpack rather than a cask. The barrel buoy is strong, and it is simple in construction, but from its low elevation above the surrounding water, it does not fulfil the most important requirement of a good sea-mark.

The can-buoy was formerly a favourite shape; it was at first always constructed of timber staves like a cask, but latterly, also of iron plate. When a can-buoy has the name of the sandbank or rock which it marks painted upon it, it is necessary to ballast one side with a small cast-iron keel, so as to ensure the name remaining uppermost. The can-buoy is not of a conspicuous form, nor does it possess any characteristic good quality which merits its being longer retained as a beacon.

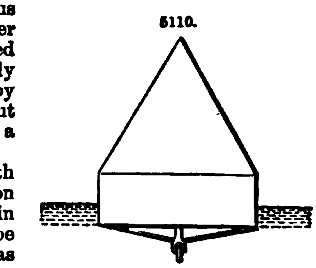
The next class of beacon buoys is characterized by a lofty superstructure, of which the cone may be considered the typical form, the body of the buoy being symmetrically disposed around a vertical axis. When the necessity for large floating beacons first arose, it may readily be conceived that a boat with a cask, or other conspicuous mark fastened to the mast, suggested itself. Wooden spars, springing from the gunwale of the boat, meet together at an apex on the mast, and present the outline of a limpet shell. A globe and bell are attached to the mast. This form of beacon is now being superseded by others specially adapted for the purpose.

Another form of beacon, still sometimes used, consists of a spar, passing through a float, or raft of solid timber, called a deadman. The spar is moored near its lower end, so that it floats vertically, and a globe or barrel may be attached to its summit.

Of beacons specially adapted for the purpose, the nun-buoy first claims attention. In its original form, it presented the appearance of two cones attached by their bases. The egg-bottomed buoy is an improved modification of the nun-buoy. Its superstructure, which is conical, like a church spire, is formed of sheet iron, riveted to a malleable or cast-iron bottom of a hemispherical form. This buoy possesses some good qualities. It is simple in construction, and so long as the sea is calm, it is tolerably conspicuous, having a lofty, though narrow superstructure, well raised above the plane of flotation, and held in an upright position by the combined weight of the metal bottom and the mooring chain. But in a tideway, or under the influence of wind, it inclines over at a considerable angle from the perpendicular, and when the waves rise, it rolls and pitches violently, so as to become an indifferent sea-mark.

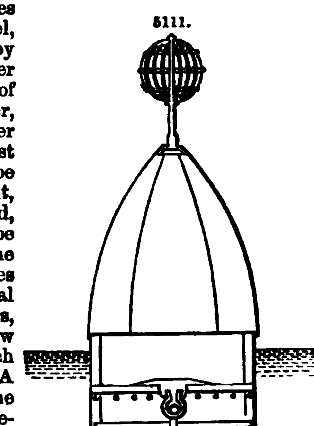
One great defect of the nun, or egg-bottomed buoy, is its want of rigidity, arising from the shape of the bottom. This defect is remedied in the buoy represented in Fig. 5110, which is made of iron. It is very buoyant, and presents a far more conspicuous object than the barrel buoy, which it has superseded in the river Liffey. The bottom is either flat or slightly coned. Flat-bottomed buoys are, however, ill adapted for the open sea, as they are only slightly immersed, and are consequently easily boxed about by the waves, which make them roll violently in rough weather; but this perhaps is of little consequence in the inner waters of a harbour.

5110.



The qualities of stability and steadiness in connection with others of great importance, such as simplicity of construction and consequent cheapness of manufacture, are combined in B. B. Stoney's keel-buoy, Fig. 5111. The superstructure may be of any of the ordinary forms, but the dome-shape is preferable as being the most conspicuous. It will be observed that the sides are prolonged below the bottom, so as to form a circular keel, within which a large body of water is retained, so that a buoy 6 ft. in diameter, with a keel of 18 in., contains within the latter a body of water exceeding a ton in weight, or a mass of water of nearly the same weight as the buoy. A buoy 8 ft. in diameter, with a keel of 20 in., contains upwards of 2 tons of water within the keel. A few air-holes are pierced in the keel, just underneath the bottom, for the purpose of letting the air escape on first floating the buoy. Thus, by a very simple arrangement, the floating mass is virtually doubled, or even further increased, if desirable; and the buoy is consequently less liable to be tossed about like a cork on the waves. Again, the bolt of the mooring chain, where it passes through the mooring ring, divides the surface exposed to lateral pressure into equal or nearly equal portions. Hence the keel-buoy floats erect in tideways or rivers, however rapid; for equal pressure is exerted both above and below the centre of mooring. The keel also gives this buoy a much greater hold in the water than is the case with other buoys. A sudden blow of the wave is resisted, as has been shown, by the inertia of the enclosed mass; but it is also resisted by the reaction of the water against the outside of the keel, especially when the buoy receives a sudden blow above the plane of flotation, a frequent occurrence in a chopping sea. Hence the tendency to pitch is diminished.

5111.



A buoy, 9 ft. in height not including the keel, and 6 ft. in diameter, projects 7 ft. 6 in. above the water; and in general, a keel-buoy may have a superstructure 25 per cent. higher than that of other buoys of equal diameter, with the same configuration above water. A keel-buoy of the size

mentioned weighs 23¼ cwt., and will, however, even before the mooring chain is attached, support the weight of an ordinary man on the summit with only a slight inclination from the perpendicular.

Works on this subject;—Smeaton (J.), 'Eddystone Lighthouse,' fol. 1813. Stevenson (R.), 'Account of the Bell Rock Lighthouse,' royal 4to, 1824. Stevenson (A.), 'Account of the Skerryvore Lighthouse,' royal 4to, 1848. Stevenson (A.), 'Construction and Illumination of Lighthouses,' 12mo, 1850. 'Report on Lights, Buoys, and Beacons,' 2 vols. folio, 1860. 'Reports from the U. S. Government on Lighthouses,' 8vo, various years. Reynaud (L.), 'Mémoire sur l'Éclairage et le Balisage des Côtes de France,' 4to and folio, 1864. Stevenson (T.), 'Lighthouse Illumination,' 8vo, 1871. See also numerous papers in the 'Minutes of the Institution of Civil Engineers,' and in the 'Annales des Ponts et Chaussées.'

LIMES, MORTARS, AND CEMENT.

All calcareous cements have lime as their basis, mixed with various other materials in different proportions, and lime is most usually found combined either with carbonic acid, in which state it forms a considerable portion of the earth's crust, or with sulphuric acid, when it is called gypsum.

The cement formed of gypsum, termed plaster of Paris, has hitherto been seldom used in architecture, except for ornamental purposes, protected from the weather.

Carbonate of lime is found either pure, that is, consisting of 436 parts carbonic acid to 564 of lime; or, mixed with alumina, silica, magnesia, or oxide of iron, in varying proportions. If a piece of carbonate of lime is calcined, the carbonic acid will be drawn off in the process, and the cohesion of its particles will be so much lessened, that granular limestone, if very pure, will fall to powder in the kiln wherein it is burnt. The lime after calcination becomes quite white, or light brown, whatever was its former colour. In this state it has lost its affinity for carbonic acid, and is termed caustic or quick lime.

Quick-lime, on being mixed freely with its equivalent of water, slakes, that is, throws out great heat, swells, and assumes the form of a fine white powder. This is hydrate of lime, in which state the affinity for carbonic acid is restored; but though at first it quickly absorbs carbonic acid from the air, the process gradually becomes slower, and it has never been found to have recovered its full equivalent. Lime, in recombining with carbonic acid, parts with the water it combined with in forming a hydrate.

To form a cement with hydrate of lime, it must be mixed with sufficient water to make a paste of the consistency required. After having been applied as a cement in this plastic form, in order that it may set, or recover its original hardness when in the form of a carbonate, it would seem necessary only to subject it to pressure, and in some cases give it access to the carbonic acid of the air.

Lime is besides usually mixed with sand, gravel, or some such extraneous matter previous to use; and their mixture, when formed into a paste with water, is termed mortar.

The distinction between the mortars made of pure and those made of impure carbonates of lime consists in this, that the former have in themselves no property which can produce setting without the presence of carbonic acid; that is practically without exposure to the air. Mortars made from impure carbonates, on the other hand, contain within themselves to a greater or less degree this property of solidifying without the assistance of the atmosphere. From this property, which enables them to harden under water, they are called hydraulic limes or hydraulic cements.

As pure lime mortar must combine with carbonic acid, that it may harden or set, and as in this combination it must part with the water contained in it, it follows that hydrate of pure lime in a state of paste, if kept moist, will remain for an indefinite period without absorption of carbonic acid, and consequently fit for use as a cement; whilst if exposed to the dry air without pressure, the small quantity of carbonic acid gas is gradually absorbed from the atmosphere; but the lime assumes the form of powdered chalk or marble, which is wholly useless as a cement, no longer forming paste with water.

It is evident, then, that for all buildings having any pretensions to importance, it is advisable to use mortar made from hydraulic lime; and where this is not to be found in a natural state, to try to produce it artificially by mixing with the carbonate of lime the ingredients which are wanting to give it hydraulic properties.

All the ingredients of the carbonated and silico-argillaceous varieties of calcareous substances are among the commonest elements of sedimentary rocks, and are thus subject to the general phenomena of deposition.

As few engineers have the means of performing for themselves the ordinary processes of analyzing limes, the following is given as a simple practical mode of testing a stone supposed to contain hydraulic lime or cement;—The stone ought to be bluish grey, brown, or of some darkish colour, as white indicates pure limestone or gypsum. On being touched by the tongue, the presence of clay ought to be quite perceptible to the taste. It should also be detected by its smell after wetting. It should only partially dissolve in diluted acid, leaving a more copious sediment than pure limestone. This may be considered the first chemical test. Should this test be satisfactory, break the stone into fragments not exceeding 1½ in. thick, and put a few of these into an ordinary fire-place, first heating them gradually, that they may not break into too many small pieces, and keep them to a full red heat for about three hours. Take out one of the fragments, and put it into a glass of diluted hydrochloric acid. Should the stone be just sufficiently calcined, no effervescence will take place, and its original colour will remain unchanged, any effervescence showing that the stone is not sufficiently burned. Should the stone be overburned, on taking it out of the fire, it will be of a darker colour than before. Having obtained a piece properly calcined, pound it to an impalpable powder, being very careful not to allow any grittiness to remain. Mix this powder with a moderate quantity of water, by means of a spatula or strong knife, on a slate or slab, and knead it into a ball between the hands. It will soon become warm; and, if it be a good hydraulic cement, it will not only harden in the heating, but if put into a basin of water it will continue hard, and go on hardening. It is better not to put it into water until it has begun to cool a little.

The proper proportion of water is between one-fourth and one-half; the addition of a larger

quantity making a very thin paste, which will take much longer to set, although ultimately the slow-setting ball will become as hard as the others. A great excess of water will, however, destroy the cement. The balls should be allowed to remain in a basin of water for a long time, taking one of them out at intervals of ten days for a month or two, and noting the hardness of their interiors. As a saturated solution of lime water would be very soon formed in the basin, the water should be changed daily, in order to ascertain the full value of the cement.

For practical purposes, Vicat's division of limes may be well adopted as follows;—

1. Fat, or common lime, which gains no consistency under water, remaining in a state of paste in water unchanged, but dissolving wholly in pure water frequently changed.

2. Poor lime, which is a combination of lime and sand, the lime in which exhibits the same phenomena, as if no sand were present.

3. Slightly hydraulic limes obtained from limestone containing 8 to 12 per cent. in all of silica, alumina, magnesia, iron, and manganese. These set in about twenty days after immersion, but in a year have not gained a consistency greater than hard soap. They dissolve in pure water, but very slowly.

4. Hydraulic limes from limestones containing from 12 to 20 per cent. of the above-mentioned ingredients; these set in from six to eight days, and in six months acquire the hardness of soft stone.

5. Eminently hydraulic limes from limestones containing 20 to 30 per cent. of the same ingredients; they set in from two to four days, and have attained great hardness in a single month. In six months they resemble the absorbent calcareous stones which bear cutting. They splinter under a blow, and present a slaty fracture.

6. Hydraulic cements from stones containing 30 to 50 per cent. of argil; these set in a few minutes, and attain the hardness of stone in the first month.

The above classification must be regarded as only approximately correct, since the hydraulic energy of limes varies with the value of the clay and the temperature at which the limestone is burned. A large proportion of iron and alumina, as compared with the silicic acid, greatly facilitates the action which takes place in calcination, and the prepared mortar also sets much more quickly. Thus Roman cement, in which the quantity of iron and alumina together nearly equals the silicic acid, is burned with little fuel at a low temperature, and the prepared cement, if fresh, sets in a few minutes. The Portland cement, on the other hand, in which the iron and alumina is less than half of the silicic acid, is burned at a very high temperature, and the cement should take as many hours to set as the Roman takes minutes.

Allusion has been made to the existence of ingredients which, mixed with pure limes, make hydraulic mortars. Of these, the two principal natural ingredients are puzzolana and trass. The former, a volcanic dust from the neighbourhood of Mount Vesuvius, in Italy, was used as early as the time of the Romans, as we find from Vitruvius; it was not used in England until Smeaton employed it in building the Eddystone Lighthouse. Trass is a similar volcanic product, found near Andernach, on the Rhine.

The chief ingredients of both of these are burnt silica and alumina; and, in imitation of them, many artificial compounds of clay have been formed, and are largely used. These are frequently termed artificial puzzolanas.

Lime Burning.—Lime kilns may be divided into two classes,—intermittent or flare kilns, in which the fuel is all at the bottom and the limestone built up over it; and running or perpetual kilns, in which the fuel and limestone are built in a similar way to that in which bricks are burned in a clamp. In the former, one charge of lime is burned at a time; and when the burning is complete the kiln is cleared out previous to burning a second; while in the latter, fresh strata may be constantly added at the top as the calcined lime is withdrawn from the bottom. In the intermittent kiln, the limestone charge rests upon arches of the same material, rudely constructed of large pieces laid dry. A small fire is lighted below these arches, and quite at the back; this is gradually increased towards the mouth as the draught increases. The opening is then regulated to secure the proper degree of combustion, new fuel is added to keep it to that point, while the air which enters by the fire-door carries the flame to all parts of the arch, acting in the manner of a reverberatory furnace, and gradually bringing the whole to a state of incandescence. Care must be taken in forming the arches that the stones of which they are formed are not such as will crack and burst with the application of heat; as they might cause the arch to give way, and the charge to fall in. The perpetual kiln is the more economical of the two in fuel, but at the same time is more difficult to manage. A mere change in the duration or intensity of the wind, a falling in of the inner parts of the charge, an irregularity in the size of the lumps of limestone used, may all be sufficient to alter the force of the draught, and to cause an excess or deficiency of calcination. A change in the quality of the fuel used will also evidently alter the time of burning; and sometimes a kiln of this description, after working for some time very well, suddenly becomes out of order without any apparent reason. So that the management of such a kiln must be an affair of experience and caution alone; but, notwithstanding the precautions required, the perpetual kiln is one very largely used.

The fuel used for kilns depends on the products of the country or district in which they stand. In England coal and coke are the only two fuels ever used. If any use can be made of the distillation of the coal, there is then an evident advantage in using coke; for the gases which the latter gives off arrive at once at their highest degree of temperature, while this temperature is only arrived at with the former at the end of this combustion, when in fact the coal is coked in the kiln. The quantity of smoke that escapes from the kiln while the coal is being burned may be taken as an indication of the combustible wasted. A kiln in which coke is the fuel will yield nearly one-third more calcined lime in a given time than one in which coal is used.

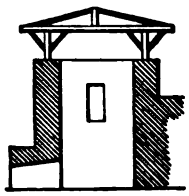
In many countries wood is the only fuel; in others wood, charcoal, and dried cowdung are the ordinary fuels. The varieties of wood of course vary with the resources of the locality. Dried

cowdung gives a slow smouldering fire, and is not a good fuel where great heat is required to calcine the limestone.

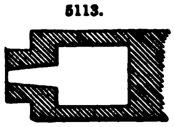
The shapes given to the interiors of kilns are very different. The object sought is to obtain the greatest uniform heat possible through the smallest expenditure of fuel, for which purpose thick walls are necessary to prevent radiation.

Figs. 5112, 5113, are of an upright rectangular prism, used in the South of France to burn both lime and bricks; the lower half of the kiln being full of the former, and the upper half of the latter, packed edgeways. This is not a construction to be recommended. Figs. 5114, 5115, are of what is termed a field kiln, and is designed for temporary use, where a large quantity of lime is wanted in a short time. It consists of an oven-shaped vault, of limestone, upon which a stack of the same material is built up in a cylindrical form. The whole is then surrounded by a wall of beaten earth, and supported outwardly by coarse wattlings. According to Vicat, in this kiln a cubic yard of lime requires from 1·64 to 2·234 cub. yds. of oak as fuel. Figs. 5116, 5117, are a form of kiln proposed by Vicat in order to ensure the upper part of the charge being properly burned without the lower part being overburned; a matter of great importance in the case of argillaceous limestones, which vitrify and become useless from overburning. To the height of 6¼ ft. it is cylindrical, above which is a conical hood of 9 ft. 10 in. in height, truncated at the vertex so as to leave an opening of about

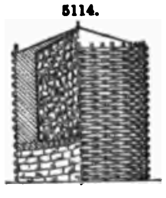
5112.



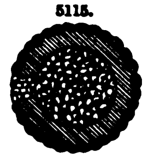
5113.



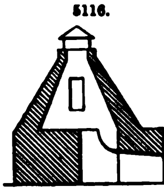
5114.



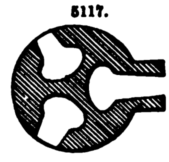
5115.



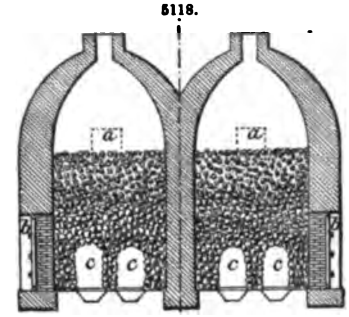
5116.



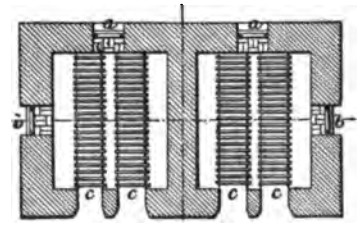
5117.



5118.



5119.



2 ft. for the escape of the smoke. The lower part is divided either into two rounded chambers, with partitions of 9 ft. 10 in. high, or into three chambers with partitions 8½ ft. high. The object of these arrangements is to avoid angular parts, where calcination always proceeds badly; to keep up the intensity of heat in the upper part of the kiln, in a way that could not be done in either of the kilns, Figs. 5112, 5114, whose walls are vertical. The partitions are intended to be adapted for the alternate calcination of the lower strata without the discontinuance of it in the upper. First, the fire in one partition is lighted and allowed to burn for two days; towards the close of that time a second fire is lighted, and the first gradually slackened, by closing the aperture; towards the end of two days more the third fire is lighted, and the second diminished, so that the upper part of the kiln will have undergone six days direct heat, while each of the lower chambers will have only had two days of more intense heat.

Figs. 5118, 5119, show a plan and cross-section of a common form of flare kiln, used for burning chalk lime on the river Medway, Kent, the fuel used being coal. These kilns are generally built in pairs, as two charges freight one river barge. *a* is a large aperture where the chalk is thrown in, the ground being higher behind; *b*, the door where the lime is taken out; *c c*, the furnaces, the bars going right across the kiln. The inside of the kiln is lined with fire-bricks, set in a mixture of equal parts of brick earth and sand, termed pug. The chalk is built over the fire-bars in two arches about 4 ft. high. Round these arches are laid large lumps of chalk, and then over these smaller pieces to the spring of the arch, packed closely in at the top. The apertures at *a* and *b* are then bricked up, and large shutters affixed to them.

When the fagot has ignited the coal, the volumes of smoke given off are apt to cause a great deal of soot to form in the kiln. This checks the draught, and to get rid of it a gun-barrel loaded with powder, and attached to a long iron stock, is from time to time forced into the centre of the furnace. The heat ignites the powder, and the explosion shakes down the soot. The lime takes sixty hours to burn, and twenty hours after they have ceased to put in fuel the lime should be cool enough to admit of its being taken out. The volume of the charge diminishes as the kiln burns; the out-turn for a pair of kilns being from 110 to 120 cub. yds. The fuel required for this quantity is 9 tons of coal, and an allowance of 1 or 2 lbs. of coarse gunpowder.

It is usual, if possible, to build kilns on the face of a steep bank, so as to be able to cart the limestone and coal up to the top, and thence to fill the kiln, and to withdraw the burned lime from the bottom.

Slaking Lime and forming Mortar.—The methods employed for slaking lime have been generally divided into three heads. The first consists in throwing on the lime as it comes from the kiln enough water to reduce it to thin paste. Too much water is generally added, and the lime is drowned, the slaking being checked. The second method of slaking consists in flinging quick-lime into water for a few seconds, and withdrawing it before the commencement of ebullition. The operation is performed by baskets, into which the lime, broken into pieces about the size of an egg, is placed. After being taken out of the water it is thrown in a heap, and allowed to fall to a powder. This method of slaking has been found to be attended by various practical inconveniences, the chief of which is the difficulty of getting the workmen to hold the lime precisely the right time under water. The third process is called air slaking, leaving the quick-lime exposed to attract moisture from the surrounding atmosphere.

It seems to matter little whether pure lime is slaked in large or small quantities at once; but with hydraulic limes only so much should be slaked at a time as can be worked off within the next eight or ten days. In order to make sure that the lime has entirely lost its affinity for water before being laid as mortar in the joints of a building, it is safer to leave hydraulic limes for from twenty-four to forty-eight hours after slaking, before making them into mortar. For want of this precaution, mortar has been known to expand and to burst even the heaviest masonry. Twelve to twenty-four hours is long enough for pure or feebly hydraulic limes; they should be left covered up during that time. Hydraulic limes should be used as fresh as possible from the kiln, and as they slake with difficulty they should be ground first, to ensure of the operation being done perfectly. Hydraulic cements do not slake at all. They should be ground to fine powder and made into mortar either in a pug-mill or by hand in small quantities, being mixed with water only when required for use; taking care not to let them remain too long in that state, as they at once begin to harden.

The quantity of water required to be thrown on the lime varies with the density and purity of the lime and its freshness; but generally speaking it will lie between $\frac{1}{3}$ and $\frac{1}{2}$ the bulk of the lime. With pure and fresh-burned lime more water is evaporated by the heat produced, than with a stale, or hydraulic lime.

The following Table shows the volumes of dry powder and lime paste produced from 1 measure of quick-lime, the volumes of water necessary, and the percentage of clay in each case;—

Designation of the lime of which the volume is taken as unity.	Volume of water used to bring it to a state of powder.	Volume produced of dry powder.	Volume of water used in all to bring to a state of paste.	Volume produced in a state of paste.	Percentage of clay in each.
1. Lime of white marble	$\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{6}{10}$	$1\frac{1}{2}$	0
2. Fat lime of Strasburg	$\frac{1}{2}$	$3\frac{1}{2}$	2	$1\frac{3}{4}$	0
3. Metz lime	$\frac{1}{2}$	$2\frac{1}{3}$	$1\frac{1}{3}$	$1\frac{1}{20}$	22·8
4. Yellow lime of Obernai ..	$\frac{1}{2}$	2	$\frac{3}{4}$	1	13·3
5. Boulogne cement	$\frac{1}{3}$	$1\frac{1}{3}$	$\frac{1}{2}$	$\frac{3}{4}$	46

It will be observed from this Table that the volumes of powder and paste produced by slaking, and the volumes of water required for the operation, are each less as the quantity of the clay present is greater. When the quantity of clay in the lime is small, the lime sufficiently predominates over it to produce by its affinity for water a violent action. Heat and vapour is thrown off, and the lime expands and falls into powder much more freely than it does in limes highly hydraulic. The cement made from Boulogne pebbles is highly hydraulic, and does not really slake at all.

Burnell makes the following important observation regarding the calcination and slaking of different limestones. "Those which are obtained from the stones containing much silica in the composition of the clay, swell in setting, and are likely to dislocate the masonry executed with them. On the contrary, those in which the alumina is in excess are likely to shrink and crack. The magnesian limestones or dolomites appear to be the least exposed to these inconveniences, and to retain without alteration their original bulk."

Sand is generally mixed with lime, however, for the sake of economy; and for ordinary purposes any good lime will stand the admixture without its properties being seriously impaired. It remains to be considered, how much sand may be thus safely used, and what kinds of sand are the best.

Theoretically the best wall is that in which the cementing material is just as strong as the brick or stone cemented. There is evidently no object in having the cement stronger; but up to the point of equal resistance, the strength of the whole wall will vary with that of the cement. In the case of fat lime, the strongest mortar that can be made of it bears such a very small proportion to the strength of a brick, that it matters comparatively little what proportion of sand is used with it. If there is much saving effected in price, 3 of sand may be used to 1 of lime, and the resistance of the mortar formed would only descend to $\frac{1}{20}$ of that of the brick. But as has been said before, such a mortar should never be used at all. With feebly hydraulic limes $2\frac{1}{2}$ cub. ft. of sand may be mixed with 1 cub. ft. of lime, and the results will be a mortar of $\frac{1}{8}$ or $\frac{1}{7}$ the resistance of brick. With hydraulic lime of good quality, such as lias lime, $1\frac{1}{2}$ to 2 parts of sand may be used to 1 part of lime, but this is the limit.

For hydraulic works and foundations, equal portions of lime and sand should be the limit allowed.

There is much difference of opinion as to what sand is best suited for mixing with lime. Vicat concluded that the advantage of the three different descriptions of sand employed by him varied with the nature of the lime. He calls coarse sand, those whose grains, supposing them round, vary from $\frac{1}{12}$ to $\frac{1}{8}$ of an inch in diameter; fine sand, where the grains vary from $\frac{1}{25}$ to $\frac{1}{12}$ of an inch in diameter; and according to this statement ranked their superiority with limes as follows;—

	1st.	2nd.	3rd.
For eminently hydraulic limes	Fine.	Mixed.	Coarse.
For slightly " "	Mixed.	Fine.	Coarse.
For fat limes	Coarse.	Mixed.	Fine.

Powder, especially when derived from calcareous substances, he found to make excellent mortar both with hydraulic and eminently hydraulic lime. He considered that the greatest difference in the hardness of mortars of fat limes, which the use of this or that kind of sand is capable of occasioning, rarely amounts to more than $\frac{1}{5}$, but it exceeds $\frac{1}{3}$ with the mortars made from hydraulic or eminently hydraulic lime. That is, if the maximum hardness in the two cases be 100, the minimum will not be far from 80 in the first case, and 60 in the second.

The general opinion of writers has been that pit-sand is better than river-sand. It is usually rougher and more angular; and whether rightly or not, it is certain that these qualities are valued by most practical builders.

Sea-sand has been condemned by most writers as the worst that can be used. Smeaton in building the Eddystone Lighthouse found mortar made with salt water just as good, if not better, than that made with fresh; so that in his case we may suppose sea-sand impregnated with salt would have made equally good mortar as fresh-water sand. Davy, in his 'Treatise on Foundations,' remarks, "it is almost unnecessary to observe that washed sea-sand will produce precisely the same effects as the best river-sand."

It is probable that the difference of opinion on this subject may arise from the different kinds of lime that have been used. Fat lime will not harden if kept damp; and the presence of salt in the mortar will always keep it so. Hydraulic limes, on the other hand, harden all the better, though not so quickly, from being kept damp; and it is therefore reasonable to suppose that in their case sea-sand is not prejudicial. For internal plastering sea-sand is evidently unfit, on account of the moisture which keeps exuding from it, disfiguring its appearance, and making the room plastered damp and unwholesome.

All writers are agreed that sand should be clean. This is a most important point, and one by no means sufficiently attended to. Good mortar can never be made where the sand is filled with earthy and loamy particles, and the fact of these particles being argillaceous adds nothing to their advantage. Treussart recommends that sand should be washed in masonry basins from 7 to 10 ft. wide, from 12 to 16 ft. long, and about $2\frac{1}{2}$ ft. deep, laid about a foot thick, water let over the sand, and well stirred up. Allowing time for the sand again to sink to the bottom, the water should be suddenly let off by a sluice at one end; and the operation should be repeated till the water passes off but slightly turbid, when the sand may be considered clean.

From the conflicting opinions on the subject of sand, we may conclude that in making ordinary mortar our present knowledge and experience would not justify any great expense in order to procure sand of any particular colour or grain, or from any particular source; but that generally sand either too coarse or too fine should be avoided.

That for ordinary buildings we should, if possible, use river or pit sand in preference to sea-sand. But if any great saving is effected by using the latter, we should not hesitate to do so; taking the precaution to wash it carefully first.

That for hydraulic buildings, sea-sand is just as good as any other.

That in all cases it is worth while to take pains to clean the sand before using it, or to make sure that it is clean.

The great rule in mixing mortar is to see that the lime and sand are thoroughly and intimately amalgamated. According to some writers, continual working and beating is also essential to the making of good mortar; this, however, is doubtful. The ingredients may be mixed by hand or in a pug-mill, or what is best of all, under a wheel, or stones revolving on edge.

The first great point to be attended to in applying mortars, is the necessity of thoroughly wetting the materials to be joined. If the moisture is suddenly drawn off any hydraulic mortar it will not harden. Dry bricks and most stones absorb a large proportion of water, so that if mortar is applied to the dry surface of a brick and another pressed on it, the whole of the moisture will be squeezed out of the mortar and taken up by the bricks, and the mortar itself will crumble into powder. Whereas if the brick is already thoroughly wetted, it will be able to absorb no more moisture, and the mortar will set as it ought.

With many compact stones, such as granite or marble, it will be sufficient to water the surface at the moment of using them. But porous materials, such as sandstones and bricks, should be allowed to soak in water for some hours before use. In a series of experiments on English bricks, weighing from $5\frac{1}{2}$ to 6 lbs., the average absorption of water was 12 oz. a brick.

The next requisite in applying mortar is that the mortar should be as stiff as it can be used, without inconvenience and without danger of all the unevennesses of the joints remaining unfilled when the bricks are forced home.

The third requisite is to prevent rapid drying of the mortar after it has been applied.

Mortar which is exposed to the action of frost before it has set, is so much damaged as to entirely impair its properties. In building, therefore, when the approach of frost is to be looked for, the foundations and the walls up to at least 3 ft. above the ground should be laid in hydraulic mortar, which will set rapidly: as the action of the frost is severest at the ground level. During severe frosts all building should if possible be suspended. If the walls are very thick the interiors

will generally be protected from the cold, and it will be enough to lay and point the exterior joints with cement or superior mortar.

Mortar is sometimes applied in a form termed grouting, that is, mixed with an excess of water, and poured liquid into the joints of the masonry. Good grouting can be made of eminently hydraulic lime and fine sand mixed with water, and poured immediately into the joints; it hardens instantly without shrinking, and solidifies all its water. Smeaton formed an excellent grouting of equal parts of lime and puzzolana. Grouting is, however, not generally approved of by engineers. Scott thus remarks of it,—"If the joints of a work are not properly flushed up, undoubtedly grouting is of great advantage, especially when dry bricks are employed in work, but the strength of grout cannot at all compare with that of good stiff mortar; for grout, when the water dries out, is merely very porous mortar, and the more fluid the grout, the weaker the work will be."

Much difference of opinion exists as to whether the mortar joints of masonry should be thick or thin.

In modern practice, in all masonry and brickwork where strength is required rather than ornament, thick beds and joints of good mortar will be useful. Thin bricks or tiles will also be better than thick bricks, as the material will be better burned, and consequently more enduring; more mortar can also be used, which in such work gives strength. Mortar may be used safely, and even with advantage, in thick beds, and joints in masonry for docks, for railway bridges, viaducts, and retaining walls; as also for warehouses, goods stations, cotton mills, tall chimneys, fence walls, and all similar structures. Reservoir walls, tank walls, and covering arches for waterworks, ought most certainly to have thick beds of good mortar. The proportion of mortar to rubble stonework should be about 1 to 3, that is, in 4 cub. yds. of rubble wall there should not be less than 1 cub. yd. of mortar. In brickwork with ordinary bricks the proportions will be 1 to 4. If thin bricks are used, or if very small stone is used for rubble-work, the proportions may be as 1 to 1, like some of the ancient work to be found at this day in Italy and the East, which is sound after centuries of time.

A good deal must depend on the quality of the mortar used, for if it be a slow-setting one, allowance must be made for the gradual settlement of the building; especially must this be considered in arch-work.

Lime Concretes.—The proportions in which lime is mixed with gravel, and other aggregates, depend on its quality and mode of preliminary preparation; but no accurate or safe proportions can be determined on in the absence of a true knowledge of the chemical value of the several ingredients. Rich limes are weak in cohesive and adhesive capacity, and, unless reduced to fine powder, will not bind. With such limes, therefore, it is not advisable to incorporate more than three or four parts of aggregates. The lime is usually obtained fresh from the kilns, and slaked with water, or at once mixed with the aggregate, when both are wetted and turned over together, but this is a very slovenly mode of making concrete, and should be avoided. The best plan to extract the utmost value from lime as a matrix is to reduce it to the finest powder either by slaking or grinding. When so prepared, and evenly sifted through a fine sieve, it can be applied with the most advantageous results. The water necessary for the mixture should be carefully applied in the form of a spray, either through a rose or other good distributor, and no wash or superfluity of water permitted. When lime thus carefully prepared is mixed with a favourable quality of aggregate, satisfactory results may be depended on. If the operator is satisfied that no disturbance will take place in the mass from unslaked lime, he may subject the concrete to a slight degree of pressure when putting it into the moulds or frames. As rich limes require more water than the poor ones, it is necessary to observe that there should be sufficient for their complete conversion into a hydrate, for, in the absence of the necessary quantity of moisture, the mass will have a tendency to disintegrate. These observations on rich limes for concrete making are offered for the guidance of those who may from circumstances be obliged to use them for such a purpose; but, owing to the many disadvantages attending their use, they should at all times be neglected if any better matrix is obtainable at a reasonable cost.

The poor or hydraulic limes are better adapted for concrete purposes, in consequence of the amount of silica which they contain. The blue lias varieties are the best; and when submitted to an amount of reduction which will enable them to pass through a No. 40 wire gauge, without leaving more than 5 per cent. of residuum, they will be found a cheap and advantageous matrix. Slaking, in the absence of grinding machinery, may be resorted to as with rich limes. Considerable misapprehension exists as to the desirability of keeping ground lime for any length of time before being used. The amount of injury which lime in a finely-powdered condition receives from exposure, arises from its avidity for moisture. If, therefore, the air is excluded from it, and the situation in which it is kept is dry, no injurious effect of any extent will arise. Smeaton's experience on this subject is conclusive; for he used Aberthaw lime with great success in important engineering works after it had been kept in casks for seven years. The present use of Thiel lime from France in the works of the Suez Canal, is also confirmatory of the possibility of using lime after it has been some time reduced to powder. The precaution, however, must be insisted on of keeping it in barrels well made, and their interior papered so as to exclude the air.

It is necessary here to explain the advantage which arises in treating the lime before it is mixed with the gravel or stones. Béton differs from concrete in its being subjected to two operations; first, the lime or cement is mixed with sand and treated as a mortar, to which afterwards is added the required quantity of aggregates. Concrete, however, as originally prepared in this country, only consisted of one clumsy operation of mixing the matrix and aggregate together. Hence it is more correct to say that béton is essentially a French process, and concrete the somewhat analogous one in England. In both cases the mixture is accomplished with the same object, although with a difference of detail. There can be no question that the béton process is the more perfect one, and, especially when the concrete is made into blocks or frames, offers great advantages over the other.

When, however, it is used, as in engineering works, in large masses in trenches, it involves a double operation; first, the preparation of the mortar, which is followed by its incorporation with the larger ingredients, such as gravel, broken bricks, or stone. When moulding the concrete the mortar can be used simultaneously with the gravel, and under such circumstances with beneficial effect. Its use in this way secures a solid mass, having a minimum of interstitial space. In all concretes it is necessary to adjust the proportions of lime, sand, and gravel, so that no vacuities will occur in the mixture. The larger the size of the aggregate the more necessary is it that attention should be paid to this point. With an aggregate of an average size of 2 in. it will be found that in every cubic yard there will be vacuities equal to 11 cub. ft., so that the mortar should be equal in quantity to the interstitial space. This vacant space will, of course, vary with the size or particles of the aggregate, and the amount of shrinkage will also fluctuate accordingly. When in a dry state it will shrink less than when wet in proportion to its specific gravity. A silicious or quartzose sand has a specific gravity of 2·6, and a solid cubic foot of it would therefore weigh 162½ lbs.—a cubic foot of water weighing 1000 oz. Sand of this kind, without being specially dried, when filled into a measure of a cubic foot however, only weighs 75 lbs.; showing that the space between the grains was nearly equal to their own bulk. The weight of sand of the above specific gravity may serve as a good guide or standard in estimating the amount of mortar that should be mixed with gravel for concrete; for the difference between the weight of a cubic foot of the aggregate, when pressed together, and 162½ lbs. will indicate the space to be filled. The difference should be as accurately ascertained as possible, although it is safer to have an overplus than too little of the necessary cementing material.

Roman Cement Concretes.—From the rapidity with which Roman cement sets, it is frequently employed in the preparation of concrete where much running water in foundations prevents lime or Portland cement concrete from setting quickly enough for such works. It cannot be used with a large proportion of aggregates, and is therefore seldom used for general concrete purposes. In house building with concrete it never can occupy, for the same reason, a valuable position; its quick-setting properties requiring great care to avoid the danger of disturbing its induration after the initial set has been accomplished. When necessary to use this cement for concrete, it is not advisable to mix it with more than four parts of aggregate in a dry state, and then carefully wet the mixture by a spray of water. Roman cement concrete should not on any account be rammed, as the action of the rammer would disturb the indurating action which speedily sets in.

American engineers use the natural cements for concrete, and sometimes with lime, and their experience of such a combination is most satisfactory. Gilmore recommends the following mode of preparation and use;—"Natural hydraulic cement, to which, under circumstances requiring only a moderate degree of energy and strength, paste of fat (rich) limes is sometimes added, in quantities seldom greatly exceeding that of the cement, is almost invariably used as the basis of the concrete mortar; and the concrete when made is at once deposited in its allotted place, and well rammed in horizontal layers of about 6 in. in thickness, until all the coarser fragments are driven below the general surface. The ramming should take place before the cement begins to set, and care should be taken to avoid the use of too much water in the manipulation. The mass, when ready for use, should appear quite incoherent, containing water, however, in such quantities that a thorough and hard ramming will produce a thin film of free water upon the surface, under the rammer, without causing in the mass a gelatinous or quicksand motion.

It will be found in practice that cements vary very considerably in their capacity for water, and that fresh-ground cements require more than those that have become stale. An excess of water is, however, better than a deficiency, particularly when a very energetic cement is used, as the capacity of this substance for solidifying water is great. A too rapid dessication of the concrete might involve a loss of cohesive and adhesive strength if insufficient water be used."

The composition of the compound mortar used at Fort Warren was—

325 lbs. dry cement, producing 3·75 to 3·85 cub. ft. of stiff paste; 120 lbs. Rockland lime, producing 4 cub. ft. of stiff paste; 19½ cub. ft. of loose sand, equal to 14½ cub. ft. well compacted. These ingredients, when well mixed, made 18½ cub. ft. of good mortar.

The mortar used in the construction of Forts Richmond and Tompkins, New York Harbour, was made by hand: when required for stone masonry or concrete, it was composed of hydraulic cement and sand without lime.

"Each batch of mortar or concrete corresponded to one cask, or 308 lbs. net of hydraulic cement powder. Four men constituted a gang for measuring out and mixing the ingredients, who proceeded to the several steps of the process in the following order;—

"First. The sand is spread in a rectangular layer of 2 in. in thickness.

"Second. The dry cement is spread equally all over the sand.

"Third. The men place themselves, shovel in hand, two on each side of the rectangle, at the angles, facing inwards. Furrows of the width of a shovel are then turned outwards along the ends of the rectangle until the whole bed is turned. The two men on one side thus find themselves together, and opposite the two on the other side, having, of course, left a vacant space transversely through the middle of double the width of a shovel. They then move back to their original positions in turning furrows as before, when the bed occupies the same space that it did previous to the first turning. The turning is executed by successively thrusting the shovel under the material, and turning it over about one angle as a pivot. Each shovel thus moves to the middle of the bed, where it is met by the one opposite, when each man moves back to the side in dragging the edge of his shovel over the furrow he has just turned.

"Fourth. A basin is formed by drawing all the material to the outer edge of the bed.

"Fifth. The water is poured into the basin thus formed.

"Sixth. The material is thrown back upon the water, absorbing it, when the bed occupies the same space that it did at the beginning.

"Seventh. The bed is turned twice by the process described above. If required for masons'

use, the mortar is then heaped up, to be carried when and where required. If for concrete (the mortar occupying the rectangular space), as at first.

"Eighth. The broken stones are spread equally over the bed.

"Ninth. A bucket of water, more or less (depending upon the quantity of stones, their absorbing power, and the temperature of the air), is sprinkled over the bed.

"Tenth. The bed is turned once as before, and then heaped up for use. The act of heaping up, which is done with care, has the effect of a second turning.

"The time consumed in making a batch of mortar is a little less than twenty minutes; in incorporating the broken stones, ten minutes more.

"Where the mortar is required in very small quantities, to avoid deterioration, instead of proceeding to the fourth step of the manipulation, the mixture of cement and sand is heaped up and the water added, and paste formed with the hoe in such quantities as are required."

The composition of the above mortar was 308 lbs. of cement powder, which produced 3·70 to 3·75 cub. ft. of stiff paste, and 12 cub. ft. of loose sand (equal to 9·75 compacted or pressed). These ingredients being incorporated, produced 11·75 cub. ft. of rather thin mortar.

The above accurately-described method of hand-mixing indicates the necessity of a careful handling of natural cement, mortar, or concrete. It is only by such a reasonable and intelligent admixture that any satisfactory results can be expected. The Rosendale cement used for these mortars gave by analysis;—

Silica, clay, and insoluble silicates.	Alumina.	Peroxide of iron.	Carbonate of lime.	Carbonate of magnesia.	Sulphuric acid.	Chloride of potash and sodium.	Water and loss.
19·80	4·40	0·76	33·90	34·06	0·32	4·78	1·56

These American cements are subjected to a high degree of pulverization, being required, under strict surveillance, to pass through a No. 80 gauge sieve, 6400 meshes to the square inch, and not leave more than 8 per cent. of residuum. One solid cubic yard of raw stone yields on an average 2700 lbs., or nine barrels of cement, exclusive of those portions rejected in assorting the burnt stone.

The natural cements, so abundant in America, differ from English Roman cements in their analyses; and in no case do they approach them in setting energy. It is therefore necessary to understand that an exactly similar treatment of them for mortar or concrete would probably be attended with less satisfactory results than those obtained by the American practice. It would be better therefore to mix the Roman cement and sand first, before adding the water, which must be distributed equally through the mass until it assumes incoherency; it may then be mixed with the gravel or stones, when it will be necessary to add another quantity of water.

Portland Cement Concrete.—Whatever advantages may be derived from the practice of preparing concretes with limes, puzzolanas and natural cements—according to their cheapness or abundance —they will bear no comparison in quality to that made from Portland cement, and in all cases where practicable a preference should be given to Portland cement concrete.

Portland cement has the great advantage that it can be made of any degree of setting energy— to set in from ten minutes to two or three days. This quick setting is, however, obtained at a sacrifice of indurating strength. The practice of making Portland cement of light specific gravity is now nearly abandoned, and an average weight of 110 lbs. the imperial bushel may be regarded as the most advantageous quality. Even a lighter weight than this will suffice for ordinary concrete, if the cement is ground fine enough.

For concrete in engineering works very large proportions of aggregates have been mixed with this cement. In the sea-forts of Copenhagen the proportions were, 1 part cement, 4 sand, 16 fragments of stones.

And a very usual proportion for foundations is 1 part of cement to 10 of sand or gravel. The proportions used in the works in connection with the Houses of Parliament were 1 of cement to 4 of sand. On the Main Drainage works, where special excellence was aimed at, the cement of the finest quality was used with only 1 of sand to 1 of cement. For foundations and backing of wharf or river embankment walls, 1 of cement to from 6 to 8 of clean Thames ballast.

The mode of preparation adopted in the case of the Thames Embankment works was not calculated to extract the highest value from the cement; being the old and now obsolete method of mixing by hand and then tipping the concrete from a height into the trench prepared to receive it. The foundations were wet, and generally speaking an excess of water was used with the mass; but notwithstanding these shortcomings in its preparation the concrete attained great hardness.

In the absence of machines for mixing the materials, the usual plan adopted is to spread the stones or gravel upon a hard surface, and upon these is spread a layer of the previously-prepared mortar; the necessary amount of water is added, and the whole mass then carefully mixed and turned with rakes and hoes. There is some danger attending the supply of water, and it is advisable to thoroughly saturate the aggregate before putting the mortar on it. In all cases of concrete or mortar making, it must be remembered that the smallest possible quantity of water should be used. When a heavy and slow-setting Portland cement can be commanded it is safest, as the danger of over-wetting is reduced to a minimum. In the manufacture of granite breccia stone we have a good example of careful concrete-making conducted on the most scientific principles. A cement was selected of a weight up to 140 lbs. a bushel when it could be obtained, and with it were mixed chippings of Bath, Portland or Anston stone, obtained from the refuse of masons' yards, broken to a uniform size seldom exceeding 1½ in., to these being added sufficient small or sandy portions to fill up the interstitial space. It was made up in batches of about half a cubic yard, and all the materials first mixed together in a dry state, proportions of cement varying with the quality of the cement and the purpose for which the stone was destined. It was slightly watered with a can having a fine rose. At this stage of the process the mass was quite incoherent, and showed but slight indications of any capacity of setting, and no induration. The mixture was

then gradually and carefully put into the iron moulds, in thin layers, and rammed incessantly with heavy iron rammers. The percussion applied effected a thorough amalgamation of the mass with so small a quantity of water as to lead to a belief in the minds of the ignorant that the concrete when liberated from the moulds would be worthless. The result, however, was on the contrary most satisfactory, and large quantities of this stone were used in London and its suburbs for paving.

The moulds used for this kind of manufacture were highly finished, and strong enough to resist the pressure caused by the incessant impingement of the rammers on the yielding body of materials. The ramming was continued until the mass was absolutely solid. After fourteen days, and sometimes less, the moulds were unscrewed, and the stone carefully lifted by mechanical means—the stones made sometimes weighing half a ton. When more than ordinary strength was required, a small portion of the soluble silica of soda or potash was added; but this was quite exceptional, and it was doubtful if any increased strength was obtained.

Portland cement is occasionally used in combination with finely-sifted slaked lime, as in the case of Coignet's bétons agglomérés. In some works performed in London, at the Thames Embankment and for sewers, stone lime was used, and after being slaked with water, it was passed through an exceedingly fine sieve; the necessary quantity of Portland cement, which fluctuated according to the quality of work and its cost, was added, with fine, sharp, clean river-sand. The whole was then put into a specially-constructed pug-mill, with a small quantity of water, and thoroughly amalgamated. From the pug-mill it was at once wheeled in barrows to the work, and there spread in layers of about 6 in. deep, being carefully raked and slightly rammed. The works in question were executed during the winter, and although under such unfavourable circumstances, the centres upon which it was placed were struck in less than fourteen days without any damage to the arches. Large works have been constructed with bétons agglomérés, and many miles of sewers have been built under Paris; arches of considerable span have been built, as well as houses and churches. It is mentioned here as an instance of the advantage of well-directed manipulation effecting successful results from comparatively inexpensive materials. There was no gravel used, and the largest piece of sand was not bigger than a pea. The appearance of the work was pleasing, and closely resembled some varieties of Bath stone in texture. By such a combination—and, indeed, in some qualities of the work without any Portland cement—the danger of using an imperfectly manufactured cement may be avoided; but the cost of sifting and subsequent mixture by the pug-mill, together with the levelling and ramming, is so great as to make it doubtful if it can be used with any advantage in a locality where Portland cement can be obtained at a reasonable rate.

Mixing.—In making the various preparations described, the degree of success will much depend on the accuracy of admixture of the various materials. Until recently the operation of mortar and concrete mixing has been performed by manual labour; but the increasing magnitude of works has necessitated the adoption of mechanical mixing, with great advantage, not only as regards cost, but with considerable improvement in the quality of the mixed materials. Many ingenious machines have been devised for mixing mortar and concrete—pug-mills, horizontal, and vertical stones, with other kindred contrivances, have been used with varying success.

At the Liverpool Docks, where the mortar used in their construction obtained a justly-deserved reputation, revolving pans were used, in which heavy cast-iron rollers rotated in a contrary direction to that of the pans. At the London Docks Extension, pans 7 ft. in diameter were used, in which revolved two stones 4 ft. in diameter, having a face or thickness of 14 in., hooped with 1¾ in. cast iron. Four pans, making fourteen revolutions a minute, each charged with 7 cub. ft. of mortar, prepared 72 cub. yds. during every twenty-four hours; and it was found the space of forty minutes, or 560 revolutions, was the time of duration which realized the best and most satisfactory results in the quality of the mortar, the adhesive value of the mortar being depreciated if the revolutions were more or less than the above number. Both of these mills were driven by steam-power.

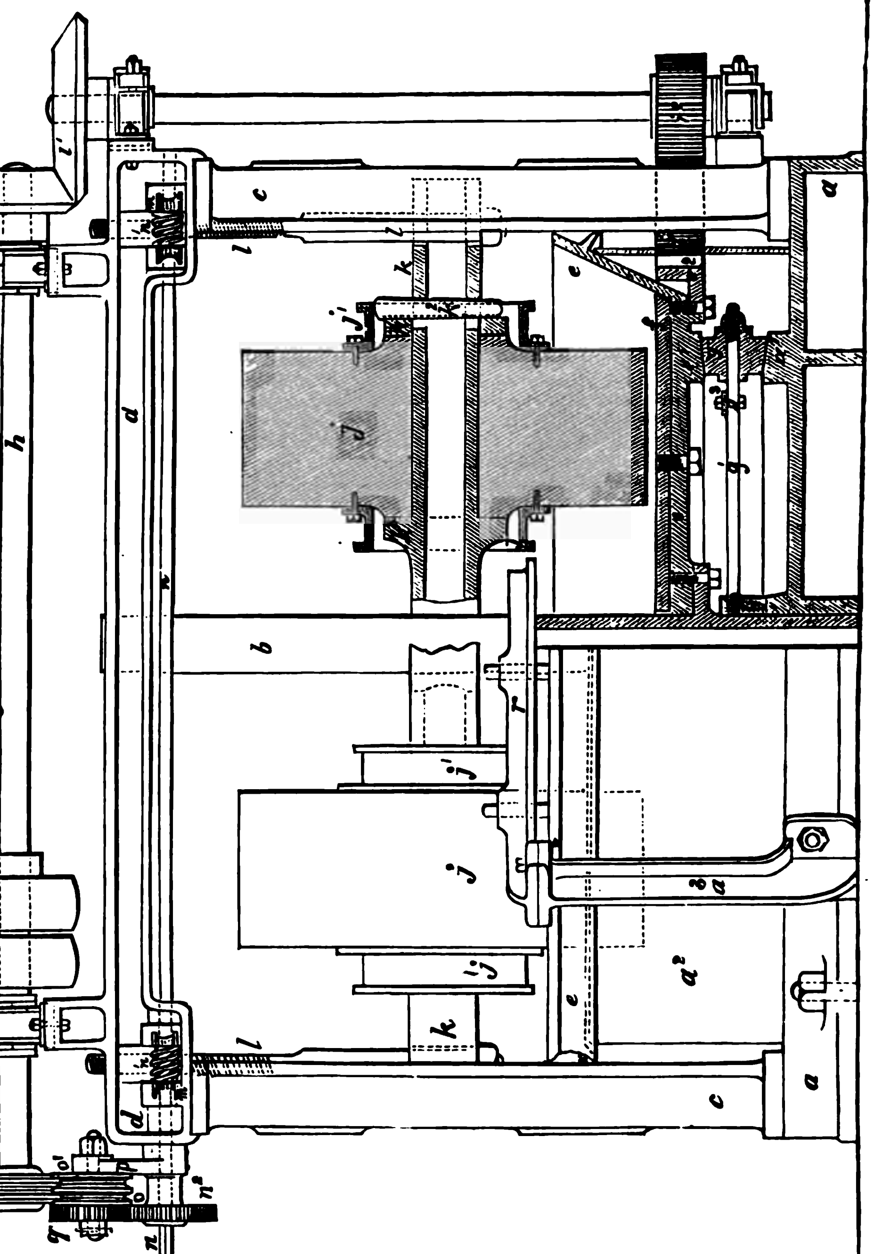
Fig. 5120 is a side elevation, partially in section, and Fig. 5121 a plan, of a mill crushing and mixing mortar. The axis of the crushing wheels j' is fixed and the motion given by a rotary bed e resting on the friction-rollers g, seen in the section, Fig. 5120. The axis k, carrying the crushing wheels j, is arranged with a vertical adjustment in the main standards c, and is with the wheels raised or lowered by means of the screws b operated by the tangent-wheels and worm n', m'. The cross shaft n, on which these worm-wheels are mounted, is driven by the corrugated friction-wheels h^2, o', connecting motion from the driving shaft h when the mill is to be filled and the wheels are to be raised, or when they are to be forced down upon the material, motion in either direction is given by means of the lever p^3 and the tumbling gearing seen in the side view, Fig. 5122. Motion is connected to the machine by means of the pulleys on the shaft h, which is geared to the vertical driving shaft on the right, by means of the bevel-wheels h', i'.

This vertical shaft is geared to the rotary bed e by means of the spur-wheel i^2, i^3, and the segment seen in the section, Fig. 5120. The crushing wheels j are kept in position on the axis k by means of the collar k^3, the key k^2, and washer k^1. The bearings of these wheels are protected from the material that falls from the top by means of the sheaths j' that are bolted to the sides of the wheels, and project beyond collars k^3 and k^1. The scrapers r' serve to collect the material in the path of the wheels, and prevent it from packing; they are held by the diagonal brackets r and standards a^2, which are bolted to the main frame.

The friction-rollers g revolve on, and are held by, the radial rods g', which are screwed into the revolving ring g^2.

Fig. 5123 is another form of mortar incorporating or mixing machine. It consists of a sheet-iron hopper A, closed at the bottom by a disc B, surmounted with a cone C, to which is imparted a quick rotary motion by the cog-wheel D. There is a rectangular opening in the hopper, 8 in. wide, the height of which can be increased or diminished by the ratchet and cog wheel F. Below the hopper is a cylindrical spout G, in which revolves a screw having iron points attached at regular intervals. Water is supplied by means of the stop-cock K, through the funnel J. Two men can work this machine by means of the crank L. If required, power can be applied by a belt to the

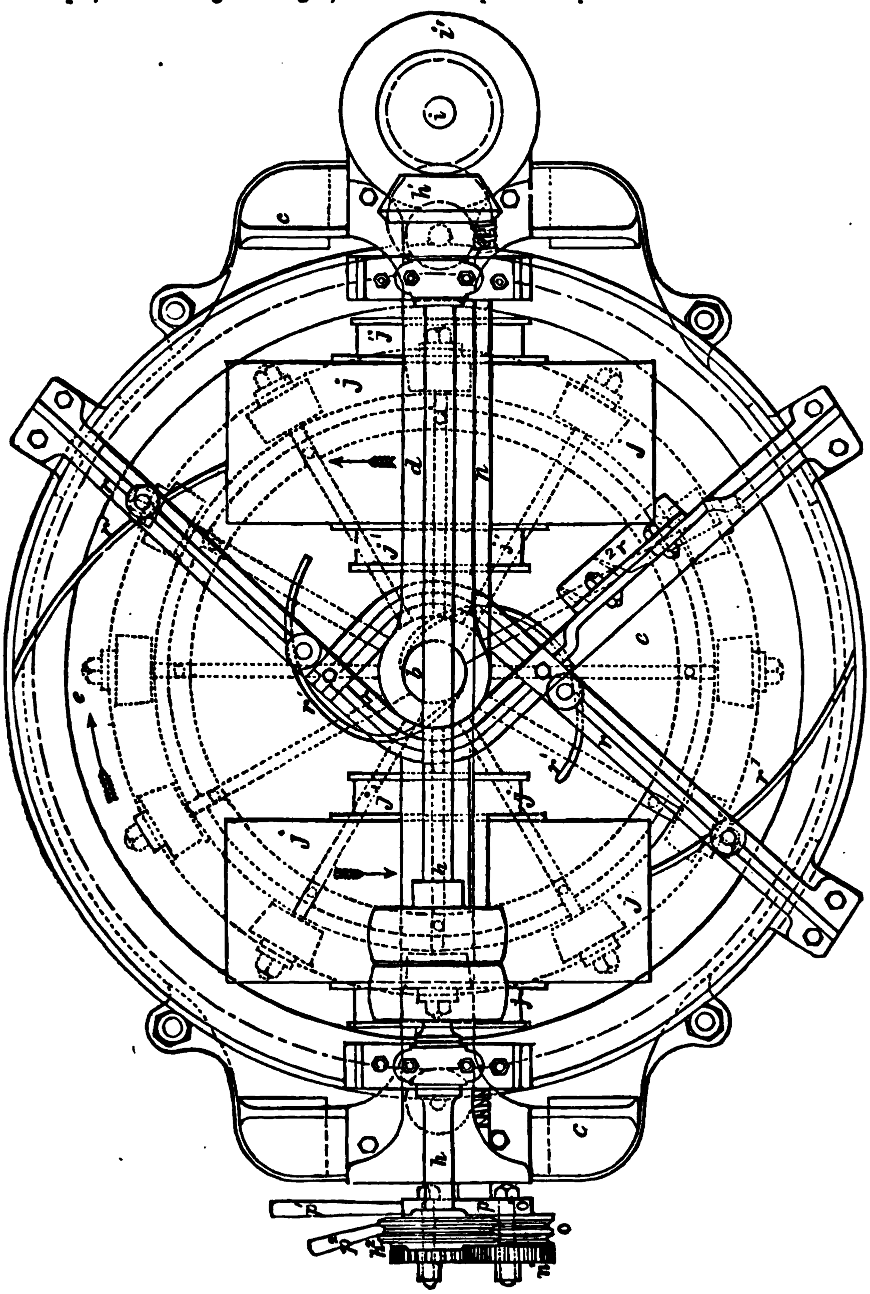
pulley O, and in a working day of ten hours, with half-horse power, it will mix 38 cub. yds. of mortar The motion of the screw carries the mortar while being mixed to the outlet, where it is discharged into buckets placed on the revolving platform M. By means of the crank N, the buckets pass in succession under the opening in the spouts. The materials before being thrown into the hopper are previously mixed dry on an adjacent platform.



5126.

Another mixing machine used for making either bèton or concrete is represented in Figs. 5124 to 5126. A valuable feature in this machine is its portable character, which enables it to be used by hand, and can be readily transferred from one point of the works to another, avoiding the cost of moving the concrete when mixed. The requisite quantities of mortar and gravel are carefully measured and put into the machine at *a*, Fig. 5124; the levers, *b b*, Fig. 5125, are then moved, the materials fall, and in descending through the several compartments are thoroughly mixed, in

which condition they reach the bottom of the machine. If necessary the machine is moved to another spot, when it is again charged, and the same operation repeated.



5121.

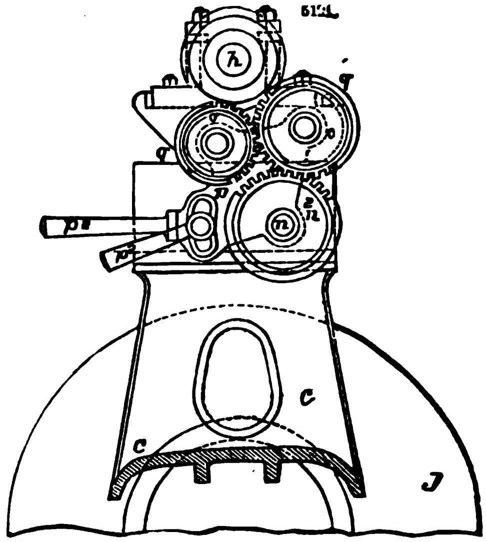
The most important object to be attained in using any of this class of machines is that of thoroughly amalgamating the materials. The necessity, in ordinary cases at least, does not arise for grinding or pulverizing them, and not only may that action be considered superfluous, but in some cases positively dangerous. The sliding action of the metal surfaces induces frictional heat, which has a tendency to evaporate the water of mixture, resulting in the imperfections due to over-grinding. It is well to avoid the use of such machines as impart this peculiar sliding action, unless on works of sufficient magnitude to ensure their careful and intelligent supervision. The simple hand-machines will be found useful in ordinary cases, and great accuracy of admixture may be realized at a comparatively small cost. The danger of excessive trituration of mortars is

not sufficiently considered, and much mischief has been caused in consequence. Portland cement mortar, when submitted to the grinding action of the mortar mill, was much impaired in quality, and after repeating experiments, at the instance of an ignorant engineer, several attempts to thus prepare it were abandoned.

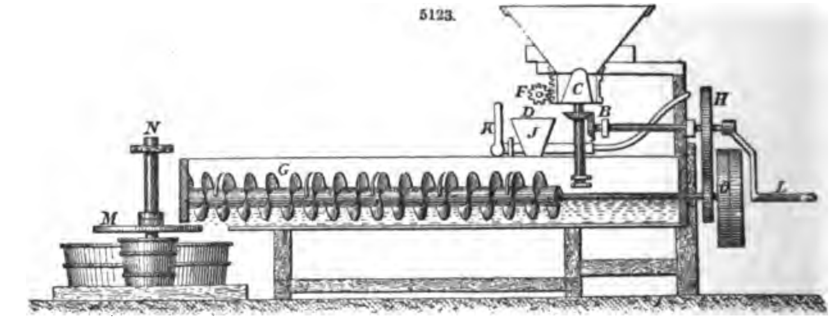
The most desirable method of mortar preparation should consist of two operations,—a thorough dusting of the aggregates with the matrix, and a careful and perfect moistening of the mass by the spray or dusting of the smallest possible quantity of water. By the first process the particles of lime and sand are placed in accurate mechanical juxtaposition, and by the second is imparted the necessary amount of moisture to sufficient chemical agglutination. Such a careful manipulation would not be more expensive than the system of mortar making which now prevails; but even if it were, the improved quality obtained would more than compensate for any increase of cost.

In building the Dirschau Bridge, West Prussia, where the cement could be made contiguous to the works, the following machinery

5122.



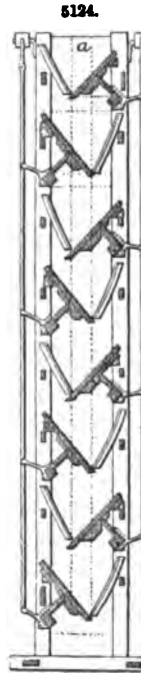
5123.



was used, combining cement grinding with the mixture of the mortar. The grinding machinery consisted of eight mortar or vertical mills, the pans of which revolve with a velocity of twenty-two revolutions a minute. The runners to each pan were provided with an adjusting arrangement, whereby the stones could be raised or lowered at pleasure. Each mill was attended by one man, who first put in the burnt cement, and, when it was ground fine enough, the water, and then the sand, was added in the proper proportions. When the cement and sand were thoroughly mixed, the mortar was withdrawn by means of a shovel—held in a contrary direction to the rotation of the pans—and placed in a hand-barrow, in which it is wheeled to the required points of the work for use.

Under ordinary circumstances such an arrangement is not desirable; but in all probability the engineer in charge of the works had special reasons for such an adaptation of the cement-grinding and mortar-mixing machinery. If the cement used was quick-setting in character, much danger was incurred by using it so freshly ground; and if of a slow-setting, hard-burnt nature, the machinery applied was inadequate to extract its greatest value. An application of such a principle is only possible where the necessary scientific control and experience is attainable at a reasonable cost.

5124.



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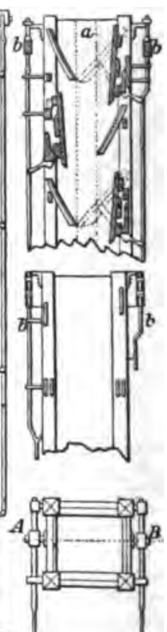
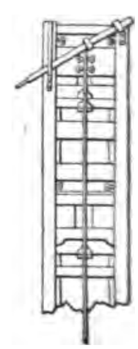


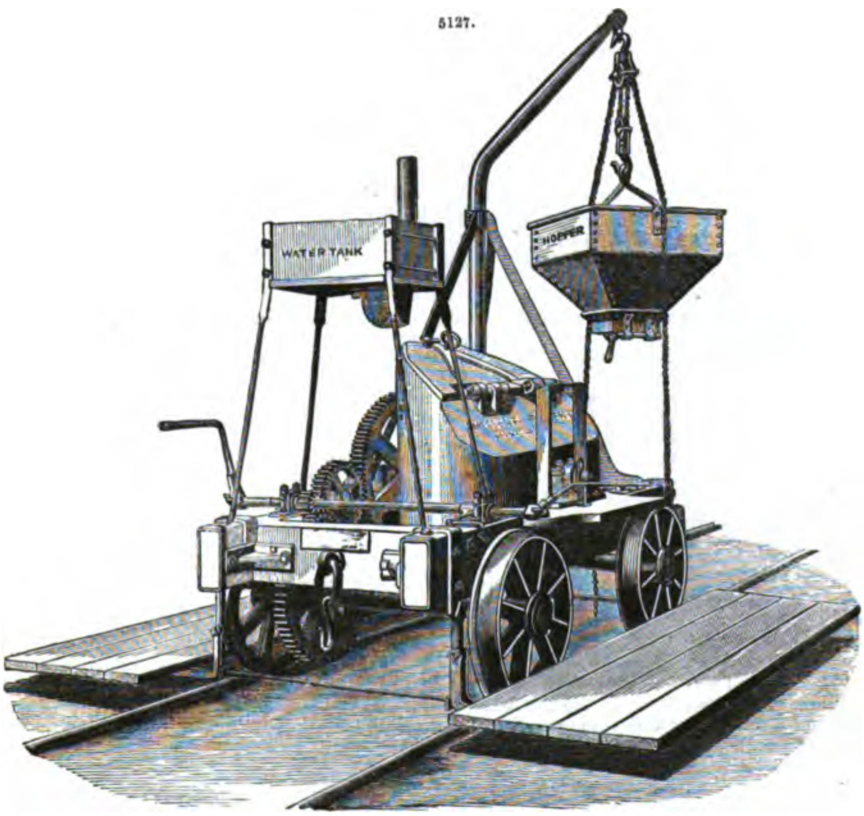
5126.



The mortar-mixing machines just mentioned may be used for concrete making where the practice is adopted of mixing the aggregates with a previously-prepared mortar, as in the case of béton, and which forms the distinction between the French material and English concrete. For concrete mixing there have been several machines used in this country, more particularly in the Main Drainage Works of London, and in the works connected with the improvement of the river Tyne. These machines were, however, of an expensive and complicated character, and their use could only be possible on works of considerable magnitude. For ordinary purposes, and in connection with house-building operations, much less complicated and cheaper machines are required, the simplest of which is that used in the construction of the bridge over the river Theiss, Hungary. In this machine the mortar was previously prepared and thrown together with the stones or aggregates into a hopper connected with a cylinder open at both ends. The cylinder was 13 ft. long and 4 ft. in diameter, inclined at an angle of from 6 to 8 degrees. The cylinder was made to revolve at a speed of twenty revolutions a minute, the power to accomplish this being applied by a driving belt placed round the exterior surface of the cylinder, which acted as a driving pulley, the inner surface of the cylinder being smooth, and lined with sheet iron. By this machine the thorough incorporation of 120 cub. yds. of concrete was accomplished during a working day of ten hours. In conjunction with such a machine a mortar-mixing mill might be judiciously combined.

Fig. 5127 is of Messent's Concrete Mixing Machine. The mixing vessel is of cast iron, of such

5127.



a shape that when half filled with material, and turned round on its axle, the material enclosed is turned over, sideways as well as endways, four times by each single revolution of the mixing vessel. It is fitted with strong top and bottom doors, and is made to revolve on its central axis by means of wheel and pinion gear, and is mounted on a trolly suited to any gauge of rails, or it may have plain wheels for an ordinary road.

A swing jib or davit at one end of the trolly carries a hopper, which contains one charge of the materials, and a tank at the other end contains one charge of water. The mode of working is as follows: the trucks carrying the material usually run on the same line as the mixing machine; the materials for one charge are filled into the hopper, which is turned over the top, and is discharged into the mixing vessel, into which the contents of the water-tank are also emptied. The mixing vessel is then set in motion, and in about seven or eight revolutions all the materials are amalgamated; the door at the bottom is then opened, and the vessel emptied.

Whilst this is being done, the hopper and tank are filled, and their contents again discharged into the mixing vessel.

Practice has shown that the best charge for the hand-worked machines is half a cubic yard, and

this quantity is turned out every six minutes, except during the changing of the empty for the full wagons; the quantity mixed a day is about 45 yds. A much better result is obtained from these machines when worked by steam, but as hand-worked machines they are found economical in cost of labour, whilst the quality of the work is far superior to that obtained by the most careful and laborious hand and shovel mixing.

This machine was specially designed by Messent to obtain a thorough mixture of materials in the large concrete blocks so extensively used in the Tyne piers at Tynemouth, and at the same time to dispense with the necessity of breaking to a uniform size the stones which are ready to hand of very irregular form and size, and it was found to accomplish the object for which it was designed with great economy in time and labour.

LINK-MOTION. FR., *Mécanisme de renversement;* GER., *Schiedersteuerung;* SPAN., *Bida articulada.*

See ENGINES, *Varieties of.* VALVES.

LOCK. FR., *Écluse;* GER., *Schleuse;* ITAL., *Conca, Sostegno.*

LOCKS AND LOCK-GATES.

Harbours which do not possess a sufficient depth of water, at low tide, to keep the vessels within them afloat, require artificial appliances to render their advantages practicably available. The means employed for this purpose is the formation of deep-water basins in which the water is retained at a sufficient level when the tide recedes. The retention of the water at such times is effected by means of gates which, though they do not fulfil exactly the same functions as the lock-gates of a canal, are yet called lock-gates on account of their common essential function of maintaining, at pleasure, two immediately adjacent bodies of water at two different levels. Beyond these gates, between the basin and the sea, there is always a walled approach or channel more or less broad subject to the motion of the tide, the chief purpose of which approach is to protect the gates from the waves of the open sea, but which also serves as a place of refuge for small craft. Sometimes half-tide basins are constructed between the approach and the deep-water basin proper. Besides these, there are in some cases dry or graving docks situate beyond the former, and requiring similar gates, though their purpose being to keep the water out instead of retaining it, they close in the contrary direction. In an able memoir read before the Society of Civil Engineers of Paris, by Sylvain Périssé, entitled 'Étude sur les Portes d'Écluse à la Mer,' Périssé states that, by reason of their position, form, and purpose, lock-gates may be classed under five heads, namely, outer or ebb gates, inner gates, sea gates, dry-dock gates, and scouring gates. Our attention, however, will be confined almost exclusively to those of the first kind.

Outer or Deep-water Basin Gates.—These gates are designed, as we have already said, to retain the water in the basin at a certain level when the tide recedes. They are placed between two side walls, which determine the breadth of the passage, and which are recessed to receive the gates when open, in order that the latter may not encumber the passage. Each gate or leaf turns about an axis, called the heel-post, standing vertically in the hollow quoin, so that when the two leaves are brought together the consequent thrust may be received by the heel-posts and transmitted to the quoins. Hence it is important that the latter should be constructed of hard stone, of large dimensions, and prepared with the greatest care.

It is indispensable to the working of the gates that a space should be left between them and the floor of the gate-chamber; and to prevent the escape of the water beneath them, as well as to afford them a lower point of support, the floor or apron is provided with a projection called a mitre-sill, the angle of which corresponds with the point of contact of the two mitre-posts.

One pair of gates is sufficient to form a basin, but in large ports two are nearly always erected, either close together, if space is wanting, or a hundred yards apart, so as to form a lock-chamber. The chief purpose of the double gates is to be prepared against an accident happening to one of them, and to enable repairs to be effected. Other advantages accrue from them, however, such, for example, as the distribution of the pressure over the two pairs, and the use of the lock-chamber as a half-tide basin, or as a wet dock. In places where the current is strong, and where the gates, if single, could not be safely worked, lock-chambers are employed, especially in times of spring tides, and when a certain number of vessels have to be taken in and out.

When the tide is coming in, the surf beats against the back of the gates often with considerable violence. The effect of this is to open the gates in spite of the pressure of the water inside, which stands at a higher level. The means to counteract this force generally employed in France is the use of *portes-valets.* These are a kind of gate usually composed of a heel-post about which they turn, and a stout top cross-piece supported by a strut resting against the lower end of the heel-post. These are erected in the opposite end of the gate-chamber, and their ends brought round till they abut against the leaves of the gates, which are thereby prevented from opening. In England *portes-valets* are unknown, partly because the ports being mostly situate in the mouth of rivers, the gates are less exposed to the action of the waves, and partly because the gates are sufficiently held by the chains connected with the hydraulic machinery employed to open them. Of course, as the *portes-valets* shut back behind the gates when the latter are open, the recess of the gate-chamber must be made deeper to receive them.

Lock-gates are opened and shut by means of chains affixed to the leaves in the middle of their height, or lower down; they are usually four in number, two on the down-stream side and two on the up-stream side of the leaves, and pass over friction-rollers and guide-pulleys to the apparatus by which they are hauled in; this apparatus is often a windlass, and the time required to open the gates by this means is frequently as long as fifteen or twenty minutes. But in this country hydraulic power is employed for all large gates, by which the time is reduced to one or two minutes at most. This is an important advantage in much-frequented ports, especially at times of spring tides.

There are two systems of letting the water in and out of the lock-chamber; one is that of sluices worked from the foot-bridge by means of a rack and pinion, as in common canal locks, in the other,

a culvert is constructed inside the side walls, and provided with sluices worked by apparatus placed upon the quays. The latter system is preferable on account of the double advantage it possesses of being more readily worked, while it does not expose the leaves to the wear and tear consequent upon the opening and shutting of the sluices, and the passage of the water. In France, these culverts are always constructed of masonry; but in England cast-iron pipes are often used, probably on account of their being much cheaper.

Inner Gates.—These are gates affording communication between two contiguous basins. They are not equal in importance to the outer gates, but they require the same careful construction, especially when the outer gates are single, as they have to replace them in case of accidents. They differ from the preceding only in their smaller dimensions, more simple working, and in having the sluices in the leaves.

Sea Gates.—The use of sea gates is to prevent the entrance of waves from the open sea; consequently they act in the contrary direction to the others. At the time of the construction of the lock, a chamber is made beyond the outer gates, having its mitre-point directed towards the approach. This chamber does not always receive a pair of sea gates, but they may be erected in case it should be required to use the chamber as a dock to examine and repair vessels in. But it is advisable to have them in harbours exposed to violent fluctuations of tide, such as are common in tropical seas. In those cases they are called hurricane gates, and are constructed of open framework, that they may fulfil their functions the better. Sometimes, especially in England, sea gates are in the form of vertical caissons, convex on the side of the sea. These caissons are floated into their position. As an example we may cite that of the Victoria Docks, constructed in 1858, and having an opening of 79 ft. from side wall to side wall, and a height of 31 ft. It weighs about 90 tons, and costs only about 2000*l.*

Dry-dock Gates.—These are a kind of floating coffer-dam, usually of iron, and of very large dimensions, as they are required to close an entrance having a breadth from side wall to side wall sometimes as great as 100 ft. But as it would be beyond the scope of the present article to enter into details concerning these gates, a description of them must be sought under other heads.

Scouring Gates.—The use of scouring basins is to wash away, by means of a strong current at low water, the deposits which collect at the bottom of the deep-water basins. The gate closing the entrance to a scouring basin usually consists of a single leaf turning about a vertical axis placed a short distance from its middle. In the larger portion there is a sluice, the dimensions of which are calculated to render the smaller predominant when the sluice is raised. By these means the water may be retained or released at pleasure. It must be remarked that by reason of the difference in the two portions of the leaf, the flood opens the gate, and the ebb closes it.

Breadth between the Side Walls.—The distance between the side walls has naturally increased with the size of vessels, and up to 1856 engineers, in consequence of the difficulty of constructing gates of large dimensions, and more especially of their great cost, had adopted the breadths absolutely necessary to the largest ship then existing, or in course of construction. Thus, from the breadth originally fixed at 40 or 43 ft. in the last century, we have passed successively to 50, 60, and 70 ft. But about the year 1856 it was deemed expedient to take into account the probable future increase in the size of sea-going ships, and an inquiry was set on foot for the purpose of determining the ratio existing between the breadth, including the paddle-boxes, of paddle-ships, and the draught of water. The results showed this ratio to be nearly constant, and equal to about 3·75. The maximum draught of water having been fixed at 24·6 ft., in consideration of existing depths both in Europe and in America, the maximum breadth of paddle-steamers was estimated at $24 \cdot 6 \times 3 \cdot 75 = 92 \cdot 25$, a breadth which has not yet been reached.

It was in consequence of these investigations that the great lock-gates of Liverpool and Havre were decided upon, having an opening of 100 ft. Since that time (1860) the breadth of the gates constructed has varied from 50 to 100 ft. in England, and from 50 to 80 in France. Now that paddle-steamers have been almost abandoned, in consequence of the nearly general adoption of the screw-propeller, this breadth is being reduced, as the hull of the largest vessels, with few exceptions, does not exceed 43 ft. in breadth. The distance from side wall to side wall which seems to be adopted now varies between 54 ft. and 72 ft.

Nature of the Materials employed.—As we have already stated in our article on Docks, it was found necessary, as lock-gates increased in size, to abandon wood in favour of iron as the material of construction. Native timber of sufficient scantling could not be obtained, and recourse was of necessity had to timber of foreign growth, such as Quebec oak, the red and yellow pines of Canada and the United States of America, Memel pine, and the green-heart of British Guinea. But, with the exception of the latter, which is expensive, and perhaps East Indian teak, which is still more expensive, all known timber when immersed in salt water is attacked by worms which destroy it in a very short time. The most common, as well as the most destructive of these, is the *Teredo navalis*, whose ravages are confined to the heart of the wood. Two means have been resorted to for the purpose of protecting the wood against these worms, one of which was to steep it in a solution of creosote. This at first gave excellent results, but is now considered insufficient. The other means consists in covering the surface of the wood with large-headed nails. This means, which is very effective, is generally adopted in France. As the worms do not ascend higher than the low-water mark of the neap tides, it is requisite to extend the nails only a short distance above this point. Under any circumstances, however, wooden gates are not very durable, and the cost of repairs is considerable. These considerations led to the adoption of iron for the principal parts of lock-gates. But these mixed constructions, in which expansion, influence of moisture, elasticity and resistance for unity of surface were so widely different, failed to realize the expectations formed of them, and they were abandoned in favour of iron alone. The first important constructions composed wholly of this material were those of the Victoria Docks, near London, erected in 1857, and in the year following others were constructed at the Jarrow Docks, upon the Tyne, on the same system. About the same time, the use of iron was rejected in France for the great gates at Havre,

and it was not till eight years later, in 1866, that the General Council of the *Ponts et Chaussées* authorized the construction, at Boulogne, of the first large gates of plate iron. In the following descriptions of the principal gates at present existing, we shall have occasion to point out the main advantages resulting from the employment of this material.

Before entering upon these descriptions, however, we must call attention to the old mode of constructing wooden gates. Originally they were braced diagonally with either single or double struts, and the cleading was generally parallel with the bracing. The latter have the disadvantage of weakening the cross-pieces, by the notches and mortises which they necessitate. Later, as the knowledge of metallurgy progressed, double iron ties, that is, applied to both the up-stream and down-stream sides of the leaves, were adopted. This enabled the cleading to be placed vertically, and so stay the cross-pieces.

The numbers to the left of our figures illustrating the examples of lock-gates refer to the various heights of the water, and all marked dimensions are on the metric system.

The Wooden Gates at Dunkirk.—These gates, Figs. 5127*a*, 5128, which were erected in January, 1856, offer several remarkable points. Each leaf has a double diagonal oak bracing, or rather strut, from the foot of the heel-post to the upper cross-piece at about two-fifths of its length from the heel-post. Additional security is given to this portion of the leaf by a tie-rod. The only bracing beyond this is a tie-rod from the upper cross-piece at the point where it receives the strut to the lower end of the mitre-post. These gates therefore furnish a good example of the simultaneous employment of the strut and tie-rod. It will be observed that the cross-pieces are weakened by the passing of the strut only in those points where the moments of flexion are relatively weak.

The cross-pieces, exclusive of the top and bottom pieces, which form with the posts a rectangular frame of native oak, are nine in number, and are of red Northern pine; these, with the upper and lower pieces, give 10 spaces, varying in height between 10 in. and 2 ft. 4 in. Each cross-piece is composed of two pieces; the one of the down-stream side is straight, and reaches from heel-post to mitre-post, a distance of 35 ft.; the other presents on the up-stream side the curve of the leaf, and is only about 29½ ft. in length for the upper cross-pieces. They are mortised into the posts, and tightly wedged and pinned. Five series of vertical oak supports or stiffeners, 12 in. × 10 in. on the up-stream side, and 12 in. × 4 in. on the down-stream side, bolted together through the leaf, and strengthened by iron bands, upon which the heads and the nuts of the bolts rest, bind, with the cleading, the cross-pieces firmly together, and at the same time serve as guides to the three sluices. The position of the latter has been determined, so that the water-ways are outside the two tie-rods. Each sluice has four water-ways 9⅞ in. high, and 3 ft. 3½ in. broad in the first, and 2 ft. 11½ in. in the other two.

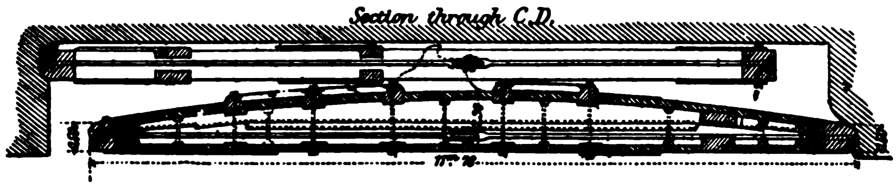
Additional strength is imparted to the leaves by two stout iron cramps upon the upper cross-pieces; a strong iron band enclosing the posts, and tightly screwed up, and, between two tie-rods 2 in. in diameter, for the purpose of holding the heel-post and mitre-post together, and maintaining rigidity in the horizontal direction. The lower end of the heel-post has a bronze socket or step, resting upon a pivot of the same metal, fixed in the masonry; at the top, the post is held vertical in the quoin by means of an iron collar, which, by means of two tie-rods, is anchored back into the masonry of the quay.

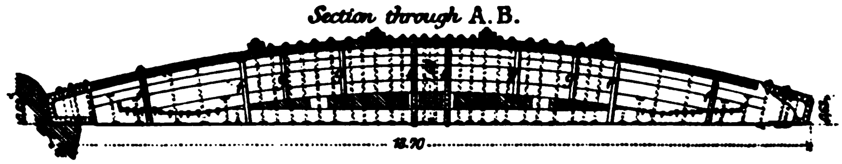
The following are the principal dimensions;—Distance from side wall to side wall, 68 ft. 10 in.; height of the upper cross-piece above the mitre-point, 23 ft. 1 in., thus giving a surface of 1573 sq. ft. Length upon the axis of a leaf, 38 ft. 7 in.; total height of the leaf, 23 ft. 9 in.; thickness of leaf, in the middle, including the cleading, 2 ft. 11 in.; thickness at the ends, 1 ft. 7 in.; thickness of the pine up-stream cleading, 3½ in.; thickness of the oak down-stream cleading, 2½ in.; breadth of the heel-post (of native oak), 1 ft. 11½ in.; breadth of the mitre-post upon the axis of the leaf, on the up-stream side, 1 ft. 10 in.; on the down-stream side, 1 ft. 3⅞ in.; mean, 1 ft. 6⅝ in.; depth of the lower cross-piece, 1 ft. 4½ in.; depth of the upper cross-piece, 1 ft. 5½ in.; depth of the four bottom intermediate cross-pieces, 1 ft. 1½ in.; depth of the five top intermediate cross-pieces, 11⅞ in.; diameter of the heel-post at the collar, 1 ft. 5⅜ in.; greatest section of the half-struts, 1 ft. 3⅞ in. × 9⅞ in.; section of the iron ties, 5 in. × 11⅞ in.; thickness of the *portes-valets*, 1 ft. 5½ in.; depth of the gate-chambers, 5 ft. 6⅝ in. The total cost of these gates was about 3000*l.* The highest level of the equinoctial spring tides, the mean level of the ordinary spring tides, the highest level of the neap tides, and the mean level of the neap tides, are marked in the figures 1, 2, 3, 4, respectively.

The Wooden Gates of the Deep-water Basin at St. Nazaire, Figs. 5129, 5130.—These gates, the side walls of which are 82 ft. apart, are worthy the attention of engineers on account of the peculiarity they possess of having no posts, strictly speaking. All the cross-pieces extend on one side to the hollow quoin, and on the other to the opposite leaf, and they terminate at each end according to the same profile. The plane surface in contact at the end is about 12 in. broad rounded off from the down-stream face with a radius of 3 in., and from the up-stream face with a radius of 9⅞ in., forming on this side a quarter of a cylinder, in the centre of which are the gudgeon and socket upon which the gate turns. In consequence of this arrangement the hollow quoins are of a special form, which seems more rational than the common round form, in order to receive the strains of compression due to the reaction of the two leaves. The lower portion of the leaf is solid up to a height of 15 ft. 9 in,, that is, formed by placing twelve cross-pieces, 15⅜ in. in depth one upon another, and held at the bottom and at the top by two other cross-pieces of iron (in plate of ⅜-in. and angle-iron 2½ × 2½), which with vertical ⅜-in. plates completely covering the two ends of the leaves, serve as a framing. Six series of intermediate pieces placed vertically on each side of the leaf and bolted together, assist in holding the twelve cross-pieces firmly together. Above the solid portion are two hollow portions, 3 ft. 1 in. in height, separated by a single cross-piece, 1 ft. 3⅜ in. in depth, like the others, and above these another hollow space, 6 ft. 6⅜ in. in height, surmounted by the top cross-piece, 1 ft. 3⅜ in. in depth. The upper part of the leaf is, like the lower, held together by a cross-piece of plate and angle iron, joined to the bands on the two ends, which bands or end plates form a series of hoops placed one above another throughout

the height of the leaf. The top and bottom pivots are of cast iron, and are as firmly fixed to the extreme cross-pieces as the system will allow. The upper pivot, which is subjected to a shearing strain, has a bolt $4\frac{1}{4}$ in. in diameter passing through its axis longitudinally, which bolt is sufficiently long to pass completely through the wooden cross-piece beneath. Each cross-piece is a

5127a.

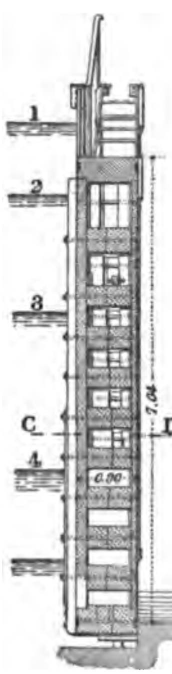




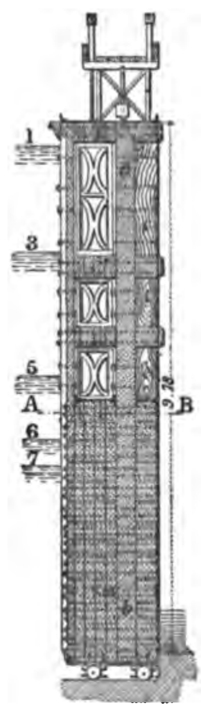
5129.

kind of trussed girder, composed of a straight tie-beam on the down-stream side, of $15\frac{3}{4}$-in. scantling, and on the up-stream side of four arched pieces, $7\frac{7}{8}$ in. thick, and placed one over the other. Two of these pieces reach the whole length of the leaf, whilst the two inner ones are notched into the tie-beam. Fig. 5129 shows between these pieces and the tie-beam, towards the middle for a length of about 20 ft., a series of spaces filled with wooden wedges driven in vertically with a monkey. These hold the cross-pieces firmly together. The cleading on the up-stream side is of wood, 3 in. thick, and extends throughout the whole height; but on the down-stream side, it exists only above the solid portion, and is of plate iron, $\frac{3}{16}$ in. thick, being bounded by the two iron cross-pieces, and having consequently a height of 17 ft. 2 in.

5128.



5130.



The lower face of each leaf rests upon two pairs of rollers, situate, one towards the middle, the other near the end of the leaf. The diameter of the rollers is only 11 in. with a breadth of 7 in. In consequence of the light load they have to bear, the floor is not provided with an iron roller path. The conditions of rolling are here evidently very bad, by reason of the insufficient dimensions of the rollers, which had to be placed in the space, $11\frac{1}{4}$ in. in height, existing between the leaf and the floor. But if it is necessary in such cases to have rollers at all, it would surely be better to adopt an arrangement which would enable larger rollers to be used.

The following are the principal dimensions of these gates;—Distance from side wall to side wall, 82 ft.; height of the top cross-piece above the mitre-point, 32 ft.; hence a surface of 2624 sq. ft. Length of a leaf upon the axis, 45 ft. 4 in.; height of the leaf, including the top angle-iron, about 32 ft. 9 in.; thickness of the leaf in the middle, 5 ft. $2\frac{1}{2}$ in.; thickness at the ends, 2 ft. $0\frac{1}{2}$ in.; diameter of the upper pivot, $11\frac{3}{4}$ in.; diameter of the lower pivot, $9\frac{3}{4}$ in.

The first pair of gates were constructed, in 1856, of Prussian red pine; but for the second pair, erected in 1859, pitch pine was chosen, which, among other advantages, possesses that of greater density. This condition of density will be recognized as of considerable importance, if we consider that, on the one hand, the weight of a leaf in air is 123 French *tonnes*, with pitch pine weighing 730 kilogrammes the cubic mètre, and that, on the other hand, the volume displaced by the solid portion of the leaf is 123 cubic mètres. The gates will therefore be very light, with the heights of water under which they are usually worked, and, supposing red pine used, it would be necessary to weight the leaves in order to ensure proper working. The first pair of gates were built vertically in their present position. The second had to be constructed in the yard, and floated to their positions. These were also built vertically. The upright position is to be chosen in all cases,

for when the horizontal is adopted, it is difficult to get at the lower side. The cost of these gates was about 7700*l*.

High water of the equinoctial spring tides, high water of the neap tides, low water of the neap tides, low water of the spring tides, and low water of the equinoctial spring tides, are marked on the figure 1, 2, 3, 4, and 5, respectively.

The Citadel Gates at Havre.—These gates, Figs. 5131, 5132, which were finished in 1862, are remarkable for their exceptionally large dimensions. The distance from side wall to side wall is 100 ft., and the mitre-point of the floor was laid 11 ft. 6 in. below the low-water level of ordinary neap tides, that is, at about 9 ft. 6 in. below the lowest tides. There are no other gates in existence so deep and broad. The large gates of the Mersey at Liverpool and Birkenhead have the same breadth, but they are not nearly so deep. The depth of water at Havre at the full neap tides is about 28 ft., so that the largest vessels may pass.

The construction of the citadel gates offered great difficulties in the matter of finding timber of sufficient scantling, and it probably would be found practically impossible to reconstruct them now on the same system. It would be necessary to introduce modifications so as to allow the employment of smaller timber, or to adopt iron.

The gates are double, and are situate 93 ft. 9 in. apart. The versed sine of the mitre-sill is between a fifth and sixth of the span, and was calculated so that the two leaves, when shut, might present on the up-stream side a single circular arc, having a radius of 107 ft. 4 in. The recesses for the gates are 59 ft. 5 in. long and 11 ft. 6 in. deep.

The top of the gates does not reach quite up to high-water level of the neap tides; but this height may be increased, if required, by the addition of removable portions. The desire to obtain gates light upon the pivot, without incurring the tendency to rise when deeply immersed in the high water of the spring tides, led the engineers to terminate the height of the gates at this level. In consequence of this arrangement the gates were suspended by ties, and they are capable of being moved without rollers, with which, however, they are provided in case of an accident lowering the water-level of the basin. Each leaf may thus rest upon *two rollers*, one situate near the mitre-post and the other at about 29 ft. 6 in. from the pivot. They are about 15½ in. in diameter and 5¾ in. broad, and they may be raised or lowered by means of jack-screws upon the foot-bridge. They roll directly upon the floor of the chamber.

Each leaf is composed essentially of two posts of French oak, connected by twenty-three cross-pieces 1 ft. in depth of Prussian pine. These cross-pieces are placed in contact one upon the other so as to form in reality only three immense cross-pieces. The bottom one consists of eighteen pieces, giving consequently 18 ft. of solid wood. The middle one consists of three pieces = 3 ft., and the top one, being composed of two pieces, has a depth of 2 ft. Each *partial cross-piece* is a solid trussed girder 6 ft. 6 in. broad in the middle, and 52 ft. 6 in. long from post to post; it is straight on the down-stream side, but presents on the side of the pressure a pretty sharp curve. The nature and construction of these cross-pieces are the same as in the St. Nazaire gates. They are firmly bound and bolted to the posts, and the various pieces of which they are composed are held together by numerous vertical and horizontal bolts, and five series of vertical stirrups. The ties are double upon each face; the longest, which is about 65 ft. long, is attached to the heel-post above the collar. The latter is in two pieces of wrought iron, and the wooden pivot which it encloses is 2 ft. 6 in. in diameter. The lower pivot and socket are of bronze, the former being fixed in the post. This arrangement renders the socket liable to become obstructed, but, on the other hand, the post is less weakened. No play was allowed between pivot and socket—a condition that is certainly open to objection. Each leaf is provided with two sluices arranged symmetrically in the first space near the two posts, in order that their projection upon the curved face may not prevent the leaf from being shut back close into the recess. The breadth of the opening of the sluice is 6 ft. 6¾ in., and the height 2 ft. 4½ in.

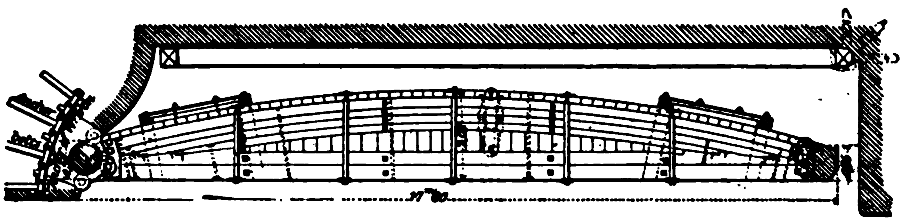
The following are the principal dimensions;—Distance from side wall to side wall, 100 ft.; height of the top cross-piece above the mitre-point, 29 ft. 8 in.; hence a surface of 2980 sq. ft. Length of a leaf from the outside of the heel-post to the middle of the part in contact, 57 ft. 6 in.; height of the leaf, 32 ft. 4 in.; total thickness of the leaf in the middle, 6 ft. 10 in.; thickness at the heel-post, 2 ft. 11½ in.; thickness at the mitre-post, 2 ft. 1 in.; breadth of the surface of contact of the two leaves, 1 ft. 3 in.; height of the mitre-sill, 3 ft. 3½ in.; space beneath the gate, 2 ft. 4½ in.; height of the foot-bridge above the leaf, 6 ft. 6 in.; height of the coping of side walls above the gate, 13 ft. 2 in.; dimensions of the heel-post, scantling, 3 ft. 3½ in. × 2 ft. 11½ in., length, 39 ft. 4 in.; dimensions of the mitre-post, scantling, 2 ft. 7 in. × by 2 ft., length, 38 ft. 8 in.; thickness of the up-stream cleading, 3½ in. The high-water level of the ordinary spring tides, high water of ordinary neap tides, mean height of water, low water of ordinary neap tides, and low water of ordinary spring tides, are marked on the figure 1, 2, 3, 4, 5, respectively.

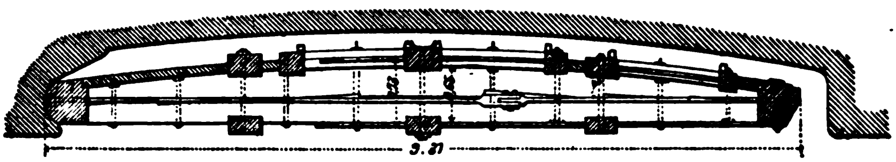
The total cost of these gates was a little over 33,000*l*.

The Gates of the Port of Dieppe.—The gates of the Duquesne basin at Dieppe, Figs. 5133, 5134, recently constructed, are remarkable for their simplicity and for the arrangement of the cross-pieces at equal distances apart. They constitute a very good type, and Levoinne, the engineer, applied, in the calculation of their wooden framework, formulæ which he had previously found for the flexion of cross-pieces bound together by a system of vertical trussing—a fact that gives them an additional point of interest.

The distance from side wall to side wall is 54 ft. 1 in., and the height of the top main cross-piece above the mitre-sill is 26 ft. 5 in. The sill is exposed at low water of ordinary spring tides, and the high water of the equinoctial spring tides rises above the gate by about 12 in. The latter is formed of an oak framing, the posts of which are connected by eight similar fir cross-pieces, forming with the upper and lower cross-pieces nine equal spaces. The vertical and equidistant pieces constitute a trussing; each of these is formed of two pieces, one 15¾ in. × 11¾ in. on the inside, and 15¾ in. × 5¾ in. on the outside, and is notched 2 in. deep over each cross-piece. The

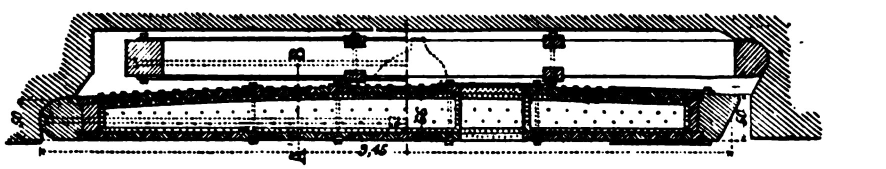
5131.



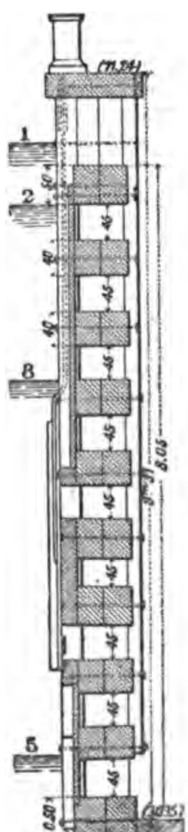


5133.

5135.

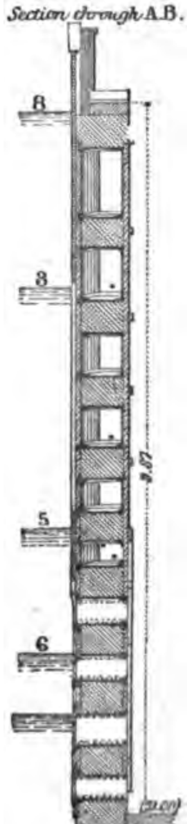


5134.

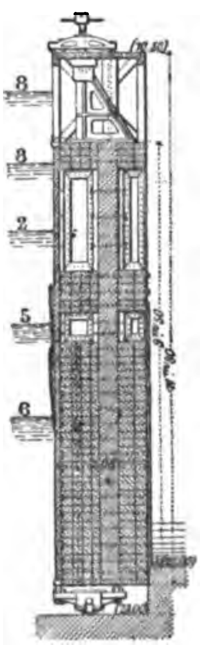


5136.

Section through A.B.



5132.



latter is formed of two pieces, the one on the down-stream side straight, the other curved and abutting upon it near the ends, the two being bound together by bolts, so as to constitute a single piece, having a thickness in the middle of 2 ft. 1 in.

The leaf is suspended upon its double-tie, the strain upon which is transmitted directly to the collar. The cleading on the up-stream side is of oak 3¼ in. thick. There are two sluices in each leaf. The total length of the leaf is 33 ft. 8 in.; the height of the leaf proper, 27 ft.; and the total height of the gate, including the cross-piece forming the foot-bridge, is 33·8 in. The gates are not nailed to prevent the ravages of worms, probably because the sill is very high, and only the bottom cross-piece is situated below the low-water level of neap tides. The figures 1, 2, 3, 4, on the vertical section, Fig. 5134, represent respectively the high-water level of the equinoctial spring tides, high water of ordinary spring tides, high water of ordinary neap tides, and low water of ordinary neap tides. The cost in this instance was about 1700*l.*

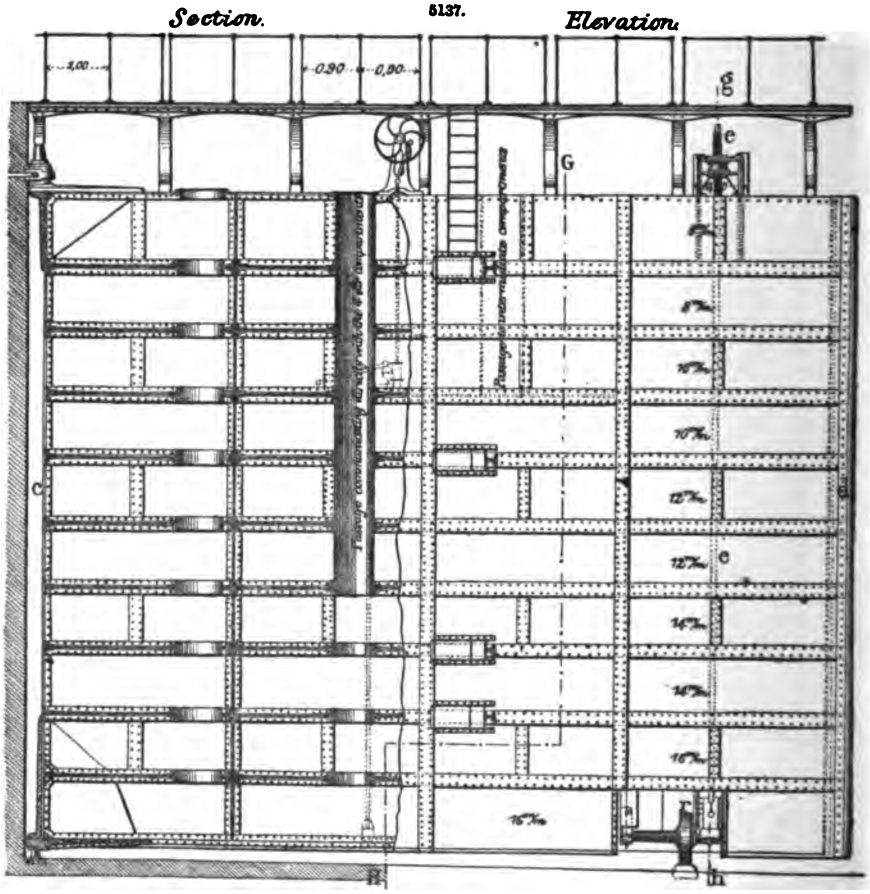
Mixed Gates at Fécamp, Figs. 5135, 5136.—These gates, which were constructed in 1864–5, we call mixed, because the cross-pieces are of wood and iron; all the other parts are of wood, and their arrangement is that generally adopted for wooden gates. We shall therefore merely give the principal dimensions. The timber used was Quebec oak for the posts and the top and bottom cross-pieces, and yellow pine for the intermediate pieces. The following are the principal dimensions;—Distance from side wall to side wall, 54 ft.; height of the top cross-piece above the mitre-point, 32 ft. 6 in.; length of a leaf from outside of heel-post to the middle of the part in contact, 31 ft. 2 in.; thickness of the leaf in the middle, 2 ft. 1¾ in.; thickness at the ends, 1 ft. 7½ in.; height of mitre-sill, 1 ft. 3¾ in.; versed sine of sill, 10 ft. 8 in.; length of the iron strengthening cross-pieces, 26 ft. 6 in.; thickness of the up-stream cleading, in yellow pine, 4 in.; thickness of the down-stream cleading, in oak, 2½ in.; scantling of the heel-post, 24 in. × 19 in.; scantling of the mitre-post, 24 in. × 19 in.; scantling of the cross-pieces, about 9 in. × 17 in.; section of iron stay (two to each cross-piece), a web of ⅜ in., and two angle-irons of $\frac{2\frac{1}{2}\text{ in.} \times 2\frac{1}{2}\text{ in.}}{\frac{3}{8}}$; section of iron ties, 5½ in. × 1⅛ in.

High water of ordinary spring tides, high water of neap tides, low water of neap tides, and low water of ordinary spring tides, are marked on the vertical section of Fig. 5156, 1, 2, 3, 4, respectively. The cost of these gates was about 4500*l.*

The Boulogne Iron Gates, constructed in 1866–7.—These are the first iron gates ever erected in a French port. They constitute the outer gates of the new deep-water basin; the inner gates being

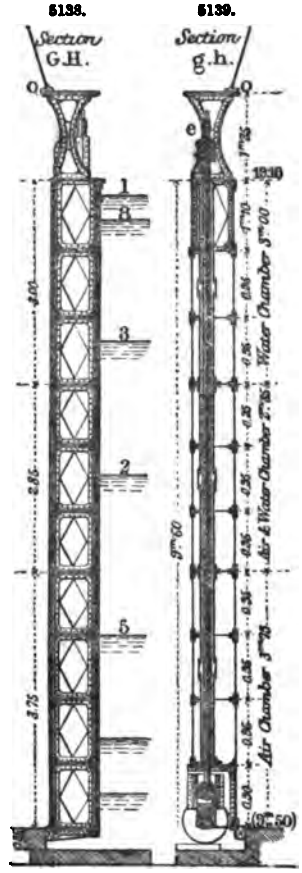
5137.

Section. *Elevation.*



constructed of wood and iron. The exceptional conditions in which these gates had to be placed, led to the adoption of iron as the material of construction. But the timidity of the engineers in this matter was such, that they determined to construct, side by side with them, wooden gates of the same dimensions. Outer gates must be capable of being opened and shut at all states of the tide, and they are exposed to the action of the surf, which, with certain winds, runs very high at Boulogne. Consequently, with this double condition, there was little ground for hesitation. Indeed, whatever the depth of water upon the sill, even if there is only 9 or 10 ft., gates must turn upon rollers, and therefore must be made as light as possible on the supposition of non-immersion. Iron possesses over wood the double advantage of giving lighter and more rigid gates; that is, better fitted to bear the exceptional strains resulting from partial immersion. And with regard to the action of the waves, iron gates are in better condition of resistance, since, being composed of hollow compartments, their weight may be increased at pleasure by letting water into them, and in this state they are less influenced by the action of the sea.

5138. 5139.

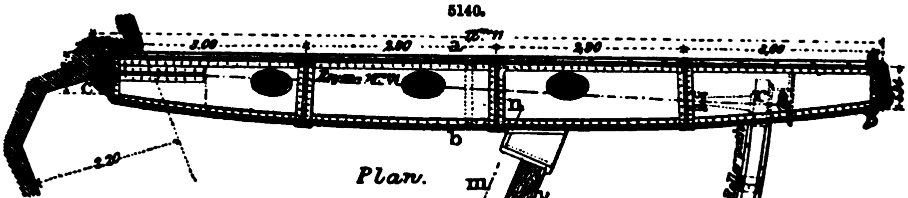


As these gates at Boulogne, Figs. 5137 to 5140, were designed by the French engineers, after a careful examination and study of the principal iron constructions of a like nature in England, they may be taken as representing the highest stage yet attained in the art of lock-gate building. We shall therefore give, in this case, a more detailed description.

The distance from side wall to side wall, Fig. 5141, is 68 ft. 10 in., and the mitre-point is situate 1 ft. 7¼ in. below the lowest equinoctial tides. The height of the gates above the sill is 31 ft. 6 in., and the equinoctial tides give a difference of level of 29 ft. 4 in.; consequently, the top of the gate exceeds the highest tide by about 6¼ in.

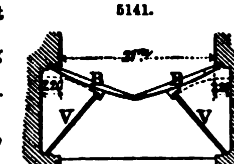
Each leaf, Figs. 5137 to 5140, may be considered as a kind of caisson, closed upon its six faces, rectangular in height, with a plane surface on the down-stream side, and a curved surface on the other, having a radius of 146·22 ft. The ends are covered with wood to serve as heel and mitre posts, not from the point of view of resistance, but only for the purpose of establishing contact between compressible pieces, and giving line of junction between the two leaves, and between the leaves and the masonry. For the same reason, the lower portions of the leaves in contact with the sill are faced with wood. The leaf is divided horizontally into ten nearly equal compartments, by eleven cross-pieces or diaphragms fixed at the ends into the shutting posts, and supported between by three vertical diaphragms of large dimensions. This arrangement is the first application lock-gates of the results of experiments made by Chevallier, to which

5140.



we shall have occasion to refer later. The leaf is divided, by water-tight diaphragms, into three horizontal chambers;—

5141.



The lower air-chamber, comprising four compartments, and having a height of 12·40 ft. from axis to axis of the plates.

The intermediate air or water-chamber, corresponding to three compartments, has therefore a height of 9·34 ft.

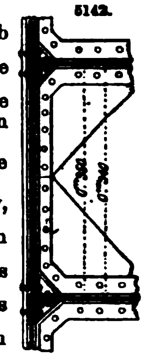
The upper water-chamber, comprising the other three compartments, having together a height of 9·84 ft.

Consequently the leaf has a total height of 31·58 ft., measured from the axis to the axis of the extreme cross-pieces. The compartments are all 3·11 ft. in height, with the exception of the bottom and top compartments, the former of which is 2·95 ft., and the latter 3 31 ft. The length of the leaf, measured from the outside of the wood-lining of the hollow quoin to the middle of the face of contact of the mitre-posts, is 40·10 ft. The height of the sill is 13·7 in., and the rise is one-fifth of the span.

Inner Cross-pieces, Figs. 5138, 5142. — These are all similar, and are in the form of double-T girders, composed of a web ·39 in. thick, four angle-irons $\frac{3\cdot15 \text{ in.} \times 3\cdot15 \text{ in.}}{\cdot5 \text{ in.}}$ and two

flanges $\frac{6\cdot 5\text{ in.}}{\cdot 39\text{ in.}}$. The height of the web in the middle is 2·88 ft., and towards the ends, 1·60 ft. The versed sine of the curve of the up-stream face is therefore 1·27 ft. These webs are in three pieces, joined by double fish-plates. Three man-holes are provided in the web of all the cross-pieces.

5142.



Bottom Cross-piece.—This also is in the form of a double-T girder, with a web ·62 in. thick, and four angle-irons $\frac{3\cdot 93\text{ in.} \times 3\cdot 93\text{ in.}}{\cdot 54\text{ in.}}$, the height in the middle being 2·95 ft., and at the ends 1·67 ft. The web and the two angle-irons on the up-stream sides is interrupted by the roller; but the requisite rigidity has been given to the chamber, where this occurs, by means of gusset-pieces.

Top Cross-piece.—The dimensions of this piece are the same as those of the bottom piece. The web is sufficiently broad to cover the skins.

Shutting Posts.—These consist of a plate 19·68 in. × ·62 in., bearing, internally, two angle-irons $\frac{3\cdot 93\text{ in.} \times 3\cdot 93\text{ in.}}{\cdot 50\text{ in.}}$, one of which, that on the up-stream side, is open at a suitable angle to receive the plates forming the skin. The heel-post has besides, externally, an angle-iron $\frac{4\cdot 71\text{ in.} \times 3\cdot 15\text{ in.}}{\cdot 50\text{ in.}}$, the short arm of which abuts upon the wood lining of the hollow quoin. To give great stiffness to these parts, which are subjected to the strains of compression due to the reaction of the two leaves, they are provided internally with a series of vertical T-irons, reaching from one cross-piece to the other.

Vertical Trussing.—In consequence of their importance, these pieces had to be constructed in the best conditions their system allowed. They could not be continuous throughout, on account of the cross-pieces forming the horizontal diaphragms, and it was necessary to have man-holes through them. To satisfy these conditions, these vertical pieces are composed, inside, of a series of quadruple angle-irons $\frac{3\cdot 93\text{ in.} \times 3\cdot 93\text{ in.}}{\cdot 54\text{ in.}}$; these angle-irons, joined together by four triangular gusset-pieces of ·39 in., are bolted to the webs of the cross-pieces and to the skins, upon which, however, a large outside plat-band or strip has been added $\frac{8\cdot 45\text{ in.}}{5\cdot 89\text{ in.}}$, extending throughout the height of the leaf, for the purpose of increasing the resistance, and with this, a series of double plates, 8·45 in. broad, forming a lining between the strips and the horizontal joint-plates. The mean horizontal distance from the outside to the outside of the strips, that is, the depth of the section of the vertical pieces, is 3·19 ft. for the central piece, and 2·87 ft. for the other two.

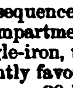
Skins, Figs. 5137, 5142.—These are the same on both sides. Their thickness varies by ·07 in., every second compartment being successively, beginning at the bottom, ·62 in., ·55 in., ·48 in., ·41 in., and ·34 in. The contract required ·69 in. for the bottom plates, but it was found in practice that plates over ·62 in. thick could not be properly tightened up by the rivets. The consequence of the substitution of ·62-in. plates was to diminish by ·19 in. the height of the bottom compartment, which is only 2·952 ft., and to add between the vertical diaphragms a framing of angle-iron, the effect of which is to make the skins rest upon nearly square panels, a condition evidently favourable to their resistance. The joints in the skins are covered with strips of plate 6·58 in. × ·39 in., which, upon the cross-pieces, double the section of the flanges. At the mitre-post end the plates are carried out 2·36 in. on the down stream, and 7 in. on the up-stream side, so as to overlap the wood.

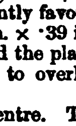
Rivetings.—The rivets are ⅞ in., and are from 2⅜ in. to 2¼ in. apart from centre to centre. The rivets in the vertical diaphragms are a little thicker, ⅞ in.

Man-hole Passages.—Each leaf has two passages affording access, one to the air-chamber, the other to the intermediate air or water chamber. Thus an inspection is at all times practicable. Their section has been reduced to the minimum in order to reserve as much space as possible for the communication ways. They are oblong in section, 1·96 ft. by 1·14 ft., two half-circles 1·14 ft. in diameter, joined by a rectangular portion of ·82 ft.

Step-piece and Pivot, Figs. 5137, 5140, 5143, 5144.—The step-piece is a massive piece of wrought iron of the same breadth as the leaf, and 5 ft. 2 in. long, and is strongly bolted to the bottom cross-piece. The brass 1·14 ft. in diameter was bored to 8·65 in., and furnished internally with a disc of steel presenting a concave surface on the lower side. The pivot is of cast steel, it is 7·87 in. in length, and 7·87 in. in diameter, and terminates in a convex surface. Thus, rotation takes place between two steel surfaces, between which it is impossible for foreign matter to get, since the socket is inverted. It must be remarked, too, that an annular space of ·39 in. is allowed between the pivot and its socket, an amount of play that seems indispensable to the proper working of the gates, when, by long service, or in consequence of the interposition of some obstacle, they have got somewhat out of shape in those parts which are in contact with the masonry. The step-piece and pivot are eccentric with respect to the quarter circle of the hollow quoin to prevent friction while the gate is being opened. The eccentricity is about an inch, measured upon the bisectrix of the angle formed by the axis of the gate when open with the continuation of the same axis when shut.

5143.





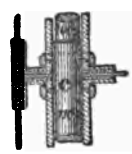
5144.

The Ring, or Upper Axis.—This is a piece of forged iron similar in form to the step-piece, except that the portion which is seized by the collar is solid, and is 11·8 in. in diameter. The collar is also of forged iron, and is held by two square iron straps 3·9 in. anchored in the masonry.

The Roller, Figs. 5137, 5139.—The fixing of this roller presents all the most recent improve-

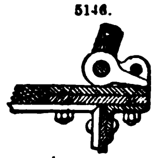
ments. Its mean diameter is 25⅝ in., and its breadth 7⅞ in. It is fixed beneath the leaf in the recess already alluded to. The roller is slightly conical, and is mounted upon a long axle, 4·95 ft., after the example of the Calais gates; this is a good arrangement, enabling the roller to work without sliding upon its path. The direction of the axle, produced towards the pivot, passes through the vertical of the centre of gravity of the leaf; its bearing inside the roller is 4·61 in. in diameter, and it penetrates a support capable of being regulated in height. The other bearing 5·90 in. in diameter, works in a fork or slot in an iron support capable of being regulated by a large vertical column of 39·3, having a screw thread on its upper portion, and held by a fixed nut upon the top of the leaf. This column passes up through a hollow cylinder, the three lengths of which, corresponding exactly with the three chambers of the leaf, are rendered water-tight and adjustable by means of right and left screw-threads which serve to compress india-rubber washers till they are brought in contact with the column, thus serving at the same time as guides. Fig. 5145 shows the tight collar through which the column passes at the floors of the chambers. The roller path is of cast iron, composed of eight segments of about 5 ft. in length, and joined by fish-plates fixed with four bronze bolts. It is 9 in. in breadth, and is sunk 17·7 in. in the masonry of the floor.

5145.

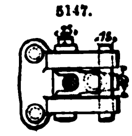


Accessory Parts.—At a height of 4·42 ft. above the leaves, a foot-board or bridge exists on a level with the side walls, provided with a hand-rail, the standards, Figs. 5138, 5146 to 5148, of which are jointed so as to allow it to be easily lowered or raised by hand. Thus when the gates are opened, no part exceeds the height of the side walls, and consequently nothing is in the way of ships passing in and out. The chain attachments, Figs. 5149, 5150, are at the extremity of the leaves and in about the middle of their height. They are stout cylindrical pieces of iron, forming a half-link, 15·7 in. in diameter, movable horizontally about a vertical axis firmly fixed to the corresponding cross-piece. Four plate-iron cheeks or brackets, Fig. 5151, faced with wood receive the thrust of the *portes-valets*, or supporting gates. Double-geared hand-crabs are used to open and shut the gates, the winding drum being, for the former purpose, 15·7 in.; and for the latter, 30·6 in. in diameter. The timber facings of the shutting sill and posts are of green-heart.

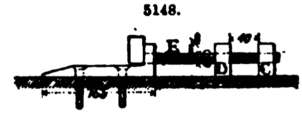
5146.



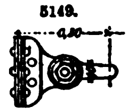
5147.

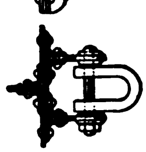


5148.



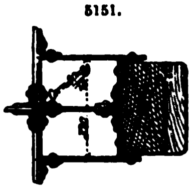
5149.



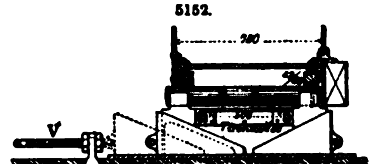


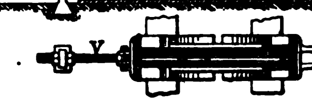
5150.

5151.



5152.





5153.

Constructing and Placing in Position.—The gates were built in the upright position in the chambers themselves. Each leaf rested upon a kind of stocks formed of double wedges, which kept it 3·93 in. above its destined final position, its distance from the hollow quoins being about 2 yds. The direction of the leaves, oblique with respect to the side walls, was such that, when continued, it corresponded with the pivot. To place them in position, therefore, a double operation was necessary, namely, a translation of 2 yds., and a descent of 3·93 in. to box the pivot; and it was requisite to perform these operations without a shock, on account of the instability of the leaf consequent on its great relative height. Two very simple and inexpensive appliances, Figs. 5152, 5153, were employed for this purpose, and by their means the gates were placed in position in a few hours. Each of these consisted of an iron roller 3·93 in. in diameter resting upon two bearing blocks kept at an invariable distance, the lower faces of which were inclined at 21° to the horizontal. An annular projection upon one end of the roller entered a straight groove fixed upon the down-stream side of the leaf for the purpose of maintaining the motion of translation in the required direction. The two bearing blocks rested upon two cast-iron wedges inclined like the blocks at 21°, but twice as long, so that by gradually increasing their distance apart by means of screws, the rollers were let down slowly and gently. When one leaf was finished, it was made to rest wholly upon the rollers by knocking out the wedge-shaped side blocks; it was then transported to its position by means of rack and pinion, and let down upon its pivot in the manner described above. The collar was then fixed and the roller frames were free to be used for the other leaf.

The various heights of the tide, namely, high water of the equinoctial spring tides, high water of ordinary spring tides, high water of ordinary neap tides, mean sea-level, low water of ordinary neap tides, low water of ordinary spring tides, and low water of equinoctial spring tides, are marked, as before, on the vertical section 1, 2, 3, 4, 5, 6, 7, respectively.

The systems and modes of construction of lock-gates adopted in this country are;—

Wooden Gates.—The old type of English gates was the same as that originally adopted in France, and which we have already described. But the necessity for larger gates consequent on the introduction of steamers led to the adoption of other systems in which timber of ordinary dimensions could still be used. The first of these systems was the *polygonal*, in which the cross-pieces constituted a kind of trusses intersected by one or more vertical pieces so as to form several panels in juxtaposition and bound with iron. The up-stream face of these gates was thus composed of a series of plane surfaces making very obtuse angles with each other. At the present time, polygonal gates are *curved*, at least on the side of the pressure, so that the two leaves when shut form on that side one cylindrical surface, whilst on the other side the two arcs or the two polygonal perimeters are not confounded.

The rise of the mean arc of the leaf is very variable; though generally included between $\frac{1}{10}$ and $\frac{1}{12}$ of the chord, it occasionally exceeds those limits. The two radii of curvature are determined carefully to obtain a proper thickness at the three principal points of the leaf, namely, the heel-post, the middle, and the mitre-post. These thicknesses are, as a mean, in the following proportions for wooden gates;—7 to 8 for the middle, 6 for the heel-post, and 4½ at the extremity of the mitre-post. Evidently there is nothing absolute in these figures. The rise given to the mitre-sill is considerable. The ratio between the span and this rise varies between 3 and 5, whilst in France it is about 5. English engineers are generally in favour of cylindrical gates; they possess undoubtedly the advantages of being more readily constructed of ordinary-size timber and of requiring less material; besides which their form, considered from the point of view of resistance, is more rational than that of straight gates, or of those curved only on the up-stream side. But, on the other hand, they have the disadvantages of requiring curved sills, which are more expensive and difficult of construction, and of being incapable of receiving support from ties. In our article on Docks we gave a Table showing a comparison between straight and cylindrical gates in various conditions, to which we must refer the reader for further information on this matter.

Weight and Volume of a Leaf.—The weight of a leaf, not including the accessory pieces fixed in the masonry, nor the small quantity of wood, the weight of which does not differ much from that of the water displaced by it, is about 66 tons. On the other hand, the volume of the two air-chambers, always immersed in the neap tides, is about 2204 cub. ft., corresponding to a lightening of 61¼ tons, say 61 tons, allowing for the weight of the water retained upon the diaphragm by the vertical arm of the angle-irons, and we have a load upon the pivot and roller of about 5 tons.

The sea communicates freely through three orifices with the upper water chamber, which consequently fills and empties itself as the tide rises and falls. This arrangement possesses the great advantage of keeping a constant weight of about 5 tons upon the pivot and roller in all tides, which enables the gates to be easily opened and shut, and prevents any sensible wear and tear of the parts in motion. In case of waves beating heavily against the gates, their air-chambers may be partially filled with water; this water may be afterwards removed by pumps.

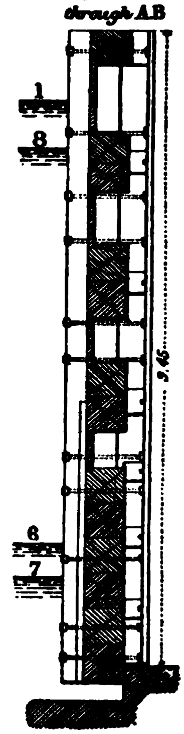
The Grimsby Docks, on the Humber, Figs. 5154, 5155.—These gates, which were constructed in 1848, are remarkable for the particular system on which they were designed. They are *straight* in form, and their cross-pieces, consisting of a single piece, are trussed with iron tie-rods.

The entrance to the docks consists of two locks, one 70 ft. broad, and 300 ft. long, and the other 45 ft. by 200 ft. We shall notice only the double gates of the larger lock. The greatest difference of level during the equinoctial tides is 23 ft. The engineer had prepared his designs for iron gates, but as oak of sufficient dimensions was found cheap, wood was adopted, and the gates are really mixed or compound, for each of the two vertical pieces on the down-stream side, which project 11·8 in., has six tension-rods attached to it, forming trussed girders with the cross-pieces. Each tie is composed of three pieces; the middle piece, of flat iron 1¾ in. × 1½ in., terminates in a fork at each end, and the others are of 2-in. round iron, having a head on one end, and a stout nut on the other, lodged in an indent at the back of each post. To ease the tenons and joints of the cross-pieces, blocks, or wedge-shaped brackets, are inserted between the cross-pieces against the posts.

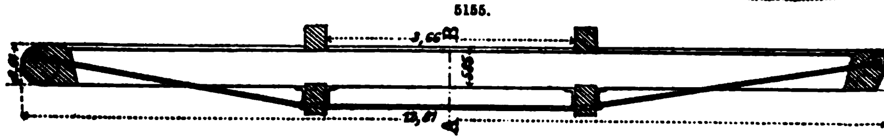
The oak cleading on the up-stream side is 3 in. thick, and is rabbeted into the cross-pieces and posts; the joints of these latter are strengthened externally by iron strips, 5 in. × 1 in., let into the wood, and bolted through, all the bolts used being galvanized. The gates, when first erected, rested upon a roller placed externally on the up-stream side; but the deformation of the leaves caused by the reaction due to this arrangement, necessitated the placing of another roller on the other side in order to bring the strain on the centre of the leaf. A cast-iron box was let into the sill to receive this roller, and provided with a special valve to keep out foreign substances.

5154.

Section through AB



5155.



The pivot and step-piece are of cast iron: the former is 9 in. in diameter, and the step is lined with bronze.

The cost of this pair of gates was 2300*l.*, exclusive of the rollers and the hydraulic machinery, of which this was the first application to dock-gates. It is worthy of remark, that *creosoting* was in this case perfectly successful; in 1864, when the gates were examined, it was found that the timber which had been subjected to the operation was quite sound, whilst other portions of 14-in. scantling, that had not been so treated, was half eaten away.

The following are some of the principal dimensions;—Span 70 ft.; height of the leaf above the mitre-point, 31 ft., thus giving a surface of 2170 ft.; length of the leaf from outside to outside, 42 ft.; height of the leaf, 32 ft.; thickness of the leaf in the middle, exclusive of the ties, 1 ft. 11 in.; thickness at the heel-post, 2 ft.; thickness at the mitre-post, 1 ft. 10 in.; height of sill, 18 in.; breadth of the parts in contact, 10 in. The weight of a leaf is about 74 tons, and the quantity of wood employed in its construction about 2200 cub. ft.

The figures 1, 2, 3, 4, on the vertical section, represent high water of the equinoctial tides, high water of ordinary spring tides, low water of ordinary spring tides, and low water of the equinoctial tides, respectively.

Wooden Gates on the Mersey.—During the last twenty years all the important lock-gates on the Mersey, at Liverpool and at Birkenhead, have been constructed on the system adopted by Hartley. The satisfactory way in which they have fulfilled their purpose, and the perfectly sound state in which they still are—even the oldest of them—have induced G. T. Lyster, chief engineer of the Mersey Docks, to continue the application of his predecessor's system. This consists essentially in the exclusive use of green-heart timber of relatively small dimensions. This purpose is effected by constructing each leaf of several smaller leaves, having each its posts and cross-pieces. These partial leaves, or as they may be called, *voussoir-panels*, are held together by tie-pieces on the concave side, and stout iron bands and bolts. The tie-pieces extend the whole length of the leaf from heel to mitre-post. The leaf is curved on the side of the pressure, and polygonal on the other side. The cleading consists of vertical planks 3 in. thick of green-heart timber, rabbeted into the cross-pieces. The shutting sills are of masonry and curved; their rise is about a fifth of the space. We have selected the Canada Dock gates as an illustration of the system.

The Great Gates of Green-heart Timber at the Canada Docks, Liverpool, Figs. 5156 to 5159.—These gates were constructed in 1857, and have a span of 100 ft. They are double and form a lock about 150 yds. in length. The gate-chambers or recesses are arched like the gates, and their greatest depth is about 7 ft. 6 in. The sill is laid bare to a depth of about 11 in. at low water of spring tides, and about 2 ft. 6 in. at the equinoctial tides. Yet the sills of the Canada Docks are lower than those of any other locks at Liverpool. It would not be desirable to have the sills lower, because the Mersey frequently brings in large quantities of fine sand. In the present condition of things, the floors of the chambers may be easily cleansed at the spring tides. The mitre-point is 19 ft. from the line normal to the side walls, and passing through the centres of the two pivots.

Each leaf is formed of four panels of about the same breadth, that is, between the heel and mitre posts are three intermediate posts, sensibly equidistant. The total height of the leaf is 35·50 ft.; but in the upper part there is a bay without cleading which reduces the virtual height to 29·50 ft. The cleading, which is 3 in. thick, is upon the up-stream side only.

Cross-pieces.—Six cross-pieces at unequal distances apart and of variable dimensions connect the heel and mitre posts. The depths of the solid and open portions of the leaf thus formed are as follows;—

	Feet.
First (bottom) cross-piece formed of 12 pieces, 6 deep and 2 thick	7·33
Space in which the sluices are	1·41
Second cross-piece formed of 8 pieces, 4 deep and 2 thick	4·28
Space with cleading	1·91
Third cross-piece formed of 6 pieces, 3 deep and 2 thick	2·86
Space with cleading	3·02
Fourth cross-piece formed of 4 pieces, 2 deep and 2 thick	2·39
Space with cleading	4·40
Fifth cross-piece formed of 4 pieces, 2 deep and 2 thick	1·90
Height of the retaining portion	29·50
Space without cleading	4·92
Sixth (top) cross-piece of a single piece	1·08
Total height	35·50

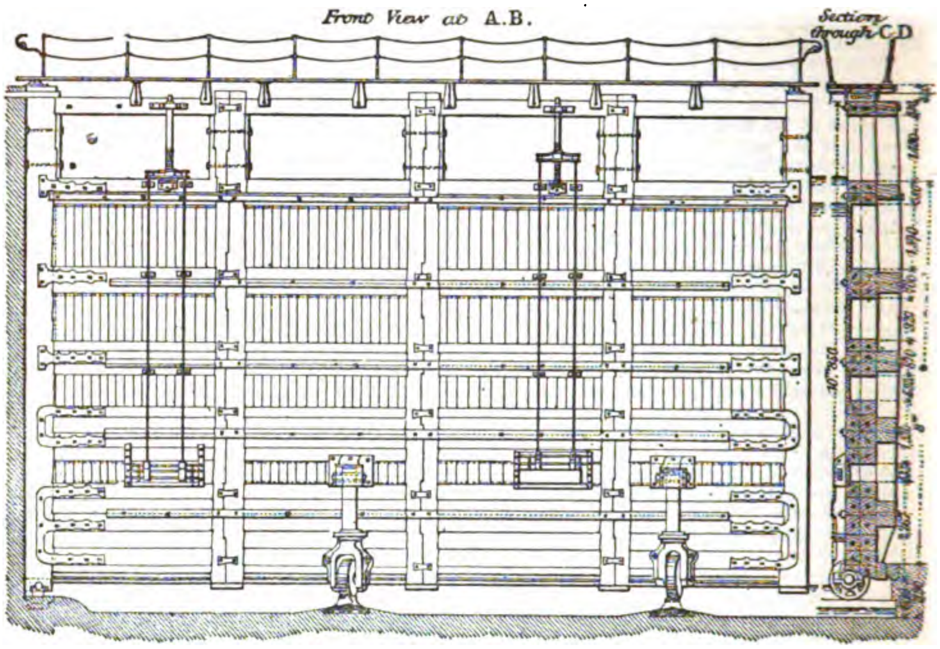
Each cross-piece is strengthened by a tie along the polygonal face of the leaf, extending nearly from one extreme post to the other. These six tie-beams have in the middle a horizontal thickness of 14·9 in., which diminishes to about the half towards the ends. The depth of these strengthening pieces is 1·80 ft. for the first two, and 1·47 ft. for the others, with the exception of the last, which is equal in depth to the top cross-piece, namely, 1·08 ft. The large bottom cross-piece has, besides its tie-beam, a piece of green-heart timber 1·47 ft. in depth, bolted flush with its under side, so as to shut against another timber facing on the shutting sill.

Taking a horizontal section of the leaf through the lower portion, Fig. 5159, we find the following thicknesses;—At the heel-post, 2 ft. 4 in.; at the first intermediate post, 2 ft. 5 in.; at the second intermediate post (the middle of the leaf), 2 ft. 2 in.; at the third intermediate post, 2 ft. 2 in.; and at the mitre-post, 1 ft. 8½ in.

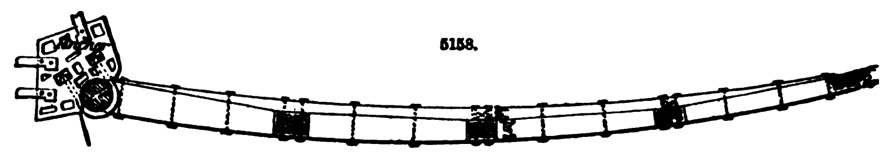
The up-stream face of the leaf is vertical throughout, and curved with a radius of 96·4 ft.; in other words, the chord joining the extremity of the diameter of the heel-post with the edge of the mitre-post being 36 ft., the versed sine of the arc is 4·17 ft. On the down-stream side the three

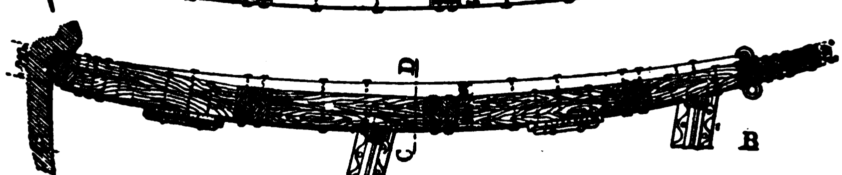
intermediate posts and the mitre-post decrease in thickness upwards from the third cross-piece, till at the top they have the following dimensions ;—First intermediate post, 1 ft. 9½ in. ; second post,

5156. 5157.



5158.





5159.

1 ft. 7 in. ; third post, 1 ft. 5 in. ; and mitre-post, 1 ft. 2 in. The cross-pieces are curved on the side of the pressure, but straight on the other side between the posts with which they are flush. It follows from this diminution of thickness towards the top that the radius of curvature, which is 96·4 ft. at the bottom, is about 124 ft. at the top, in consequence of the flattening of the leaf.

The Heel-post.—The heel-post is 2 ft. 6 in. square in section, and about 37 ft. 3 in. in height, as it stands several inches above the top cross-piece and extends the same distance below the lowest. Its ring or upper axis is 21·6 in. in diameter, and is covered with a cast-iron cap 25·5 in. in outer diameter, upon which the wrought-iron collar fits. To the lower end of the post a bronze step-piece is fixed. The horizontal section shows that it is formed of four pieces, two rectangular, and two in the form of a quarter circle, that is, a sector equal to the quadrant, all unequal in size to prevent the joints from being in line with each other. The pieces are held together by three rectangular keys of green-heart of 1 in. square section, tightly fitting two grooves running from top to bottom in two adjacent pieces, and three systems of bolts. The first, of 1½ in. diameter, hold the two rectangular pieces together. The second, placed in the direction of the length of the leaf, hold each rectangular piece to its adjacent sector-piece. The heads and nuts are deeply countersunk. The third group of bolts, 2 in. in diameter, hold the cross-pieces against the post. For this purpose a hole was bored to a depth of 2 ft. into the end of each portion of the cross-piece, and the bolt fixed in by means of a kind of key passed through transversely. The projecting portion of the bolt is provided with a nut countersunk into the back of the post. The face of the post is notched to receive the cross-pieces, which are thus lodged in indents and fished on both sides.

The Mitre-post.—The mitre-post is in one piece. A section through any point below the middle